AN INVESTIGATION INTO THE SCALING CONFIDENCE OF FLOATING TIRE BREAKWATER MODEL TESTS.

William Lloyd Nelson

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AN INVESTIGATION INTO THE SCALING CONFIDENCE OF FLOATING TIRE BREAKWATER MODEL TESTS

BY

WILLIAM LLOYD NELSON

A thesis submitted in partial fulfillment
of the requirements for the degree of

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1978

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LIST OF SYMBOLS

Symbol	Description
C_t	Transmission Coefficient
F	Wave Generator Frequency Setting
F_i	Inertial Force
F_g	Gravitational Force
H_b	Beach Reflected Wave Height
H_i	Incident Wave Height
H_t	Transmitted Wave Height
H_r	Breakwater Reflected Wave Height
L	Wavelength
L'	Linear Dimension
L_o	Deepwater Wavelength
M	Breakwater Mass
T	Wave Period
V	Velocity
W	Breakwater Width
d	Still Water Depth
e	Generator Drive Wheel Eccentricity
f	A Dimensionless Function
g	Gravitational Acceleration
h	Breakwater Freeboard
ℓ	Breakwater Length
y	Breakwater Draft
m,p,r	Subscripts for Model, Prototype, and Ratio Values

Symbol	Description
m , m'	Mass and Transformed Mass
t , t'	Time and Transformed Time
x , x'	Distance and Tranformed Distance
α , β , ϕ	Scaling Relationships
ν	Kinematic Viscosity of Fluid
ρ	Mass Density of Fluid
Π	Pi
$\mathbb{F}$	Froude Number
$\mathbb{R}$	Reynolds Number

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CHAPTER I

INTRODUCTION

With the rapid growth of prospective floating breakwater installations, there has developed a need to anticipate their performance accurately and cost effectively. Offshore, coastal, and inland wave-dependent water-born activities have utilized both physical and analytical techniques to accomplish this goal. Analytical computer models, which can investigate breakwater response through dynamic force accountability and ship motion theory, are generally used in conjunction with experimental evaluations for verification of results. Consequently, cost effective and therefore generally smaller breakwater testing facilities are sought which can adequately simulate prototype response.

Kamel and Davidson (reference 9) conducted model tests for a floating tire breakwater (FTB) called the "Wave Maze". Using six-inch outside diameter tires, they compared their laboratory results with "Wave Maze" field data compiled by Noble (reference 13). Their results indicated an inability to adequately model viscous and mooring load effects at reduced scale due to decreased flexibility of the model tires.

A modular floating tire breakwater (FTB) has been advanced by the Goodyear Tire and Rubber Company and subjected to various field tests over the past four years. In an effort to develop widely applicable FTB design curves, controlled prototype tests of the Goodyear configuration were conducted by the Coastal Engineering Research Center (CERC) at Fort Belvoir, Virginia (reference 6). Model study verification of the CERC findings was conducted by Harms and Bender using 6- and 3-inch

model tires (reference 7). In a draft report they indicate adequate model response for both model sizes, which differs from Kamel and Davidonson's conclusion. Some question as to the limit of scaling adequacy therefore exists.

It is the primary objective of this study to take advantage of CERC's recent (1978) research and to investigate the similitude validity of further reduced scale ratio tests as applied to the Goodyear FTB. Since the CERC prototype data was obtained in a large lab facility with monochromatic waves, this allowed the uncommon opportunity to test prototype and models under similar, controlled conditions. Tests were conducted with 1.6-inch and 6-inch model tires which correspond respectively with nominal 1:18 and 1:5 scaling ratios. Accountability of Froude scaling and dynamic similitude suppositions are compared at these two scales with the prototype results derived by CERC. Breakwaters which had 3, 4, and 6 modules in the direction of wave advance were tested at water depths of 2.75 and 1.5 feet for the 1:5 scale. Depths of 0.67 and 0.33 feet were similarly used for the 1:18 scale.

CHAPTER II

BACKGROUND

As outlined in the introduction, this study applies the techniques of dimensional analysis to compare the performance of a relatively new floating breakwater. In this chapter, the pertinent theoretical modeling considerations are reviewed. Additionally, floating breakwater nomenclature, their attenuation mechanisms, and the Goodyear prototype are introduced.

II - 1 Theoretical and Physical Modeling Concepts

Dimensional analysis has been employed for three centuries to correlate measurable quantities associated with various natural phenomena (reference 2). By providing appropriate dimensionless groupings of variables, the technique suggests pertinent ways of linking the results together. Its application to physical hydrodynamic modeling has provided both rapid and economical inquiries into engineering problems. Although this technique does not generally provide a complete analysis as in an analytical equation of motion solution, acceptable correspondence between model and prototype performances usually will exist if the basic laws of physics are considered in model design. Theoretically, dynamic similarity must be achieved to attain viable model data. This condition exists when the prototype to model ratio of fluid particle forces and masses are preserved . Tacit to this condition are geometric and kinematic similarities. That is, corresponding dimensions must be in proportion and the motion and paths of homologous par-

ticles commensurate (reference 15). Analytically stated, two dynamically similar fluid motions are described by a coordinate system relating the fundamental units mass (m), time (t), and distance (x), by the transformations:

$$m' = \alpha m \qquad \text{2-1A}$$

$$t' = \beta t \qquad \text{2-1B}$$

$$x' = \phi x \qquad \text{2-1C}$$

where α, β, and ϕ are scaling relationships, and (') indicates the transformed unit.

Application of dynamic similitude to hydraulic modeling is complicated by the presence of several natural forces, all of which could only be accounted for in a prototype investigation. They include: gravity, pressure, viscosity, surface tension, and elasticity forces. Besides the customarily used "inertial force", only one other force generally predominates. In the case of gravity wave models with a free liquid-surface under air, the gravity force generally prevails. Therefore, as in this study, the conventional Froude relationship of inertial to gravity forces is utilized to determine pertinent model parameter dimensions. Some of the important relationships are:

$$\mathbb{F} = \frac{F_i}{F_g} = \frac{\rho V^2 L'^2}{\rho L'^3 g} = \frac{V^2}{L' g} \qquad \text{2-2A}$$

$$L'_r = \frac{L'_m}{L'_p} \qquad \text{2-2B}$$

$$T_r = \sqrt{L'_r / g_r} \qquad \text{2-2C}$$

$$F_r = L'^3_r \rho_r g_r \qquad \text{2-2D}$$

where,

$\mathbb{F}$ = conventional Froude number for free liquid-surface flow under air

F_i = inertial force

F_g = gravitational force

ρ = fluid density

g = gravitational acceleration

V = velocity

T, L' = time and linear dimensions

m,p,r = subscripts for model, prototype, and ratio values

Several simplifications and assumptions are necessary in the direct application of conventional Froude modeling. For example, the model to prototype ratios of fluid density and gravity are generally considered as unity. In models, viscous forces are relatively greater than in the prototype, which can lead to alterations in the flow process. Since it is infeasible to simultaneously model Reynolds and Froude criteria in the same fluid, viscous effects are ignored due to their secondary importance. Similarly, surface tension effects are usually considered as negligible, especially for wavelengths greater than 0.5 feet (reference 15). Model structure elasticity parameters also must be assumed to respond such that all relative force magnitudes are preserved. Aberrations due to some of these assumptions are investigated in this physical modeling study of floating breakwaters.

II - 2 Floating Breakwaters

Floating breakwaters are essentially displacement vessels at anchor which protect their lee via the attenuation of incident wave energy flux. Performance of these structures is a function of both the local wave climate and their own inherent structural response. Wave attenuation and the reduction of wave energy transmitted in the direction of wave propagation are generally a combination of one or more of the following mechanisms:

1 - wave reflection and the regeneration of waves seaward

2 - the transformation of wave orbital motion into random turbulent motion

3 - the production of wave breaking conditions

4 - hydraulic damping via the interaction of water particles with the breakwater

5 - out-of-phase damping

6 - viscous damping

7 - wake drag

In order to minimize transmitted wave power attributable to structure motion, breakwaters must have natural frequencies that are very low compared with the wave frequencies to which they will be subjected.

Floating breakwaters have several advantages (primarily economic) over their gravity counterparts since installation is only slightly dependent on depth and bottom conditions. Unaltered hydrography and the non-impedance of tidal and littoral flows is to their advantage in

the maintenance of water quality. Additionally, they can provide a substratum for marine growth without obstructing normal fish migration. However, floating breakwaters are not a panacea. Complete incident wave attenuation is rarely achieved as in many fixed structures. Conservative designs and therefore increased project costs are often the result of loading uncertainties and maintenance costs.

Since floating breakwaters have the potential to fail instantaneously, for example by the parting of a mooring line or the fracture of some interconnecting hardware, their design is a critical procedure dependent upon local conditions. The nomenclature applicable to floating breakwaters is graphically portrayed in Figure 1. Parameters include:

H_i = incident wave height

H_t = transmitted wave height

H_r = breakwater reflected wave height

H_b = beach reflected wave height

L = incident wave length

y = breakwater draft

h = breakwater freeboard

W = breakwater width

d = water depth

M = breakwater mass

Some comparative relations of importance are:

$C_t = H_t / H_i$ = transmission coefficient

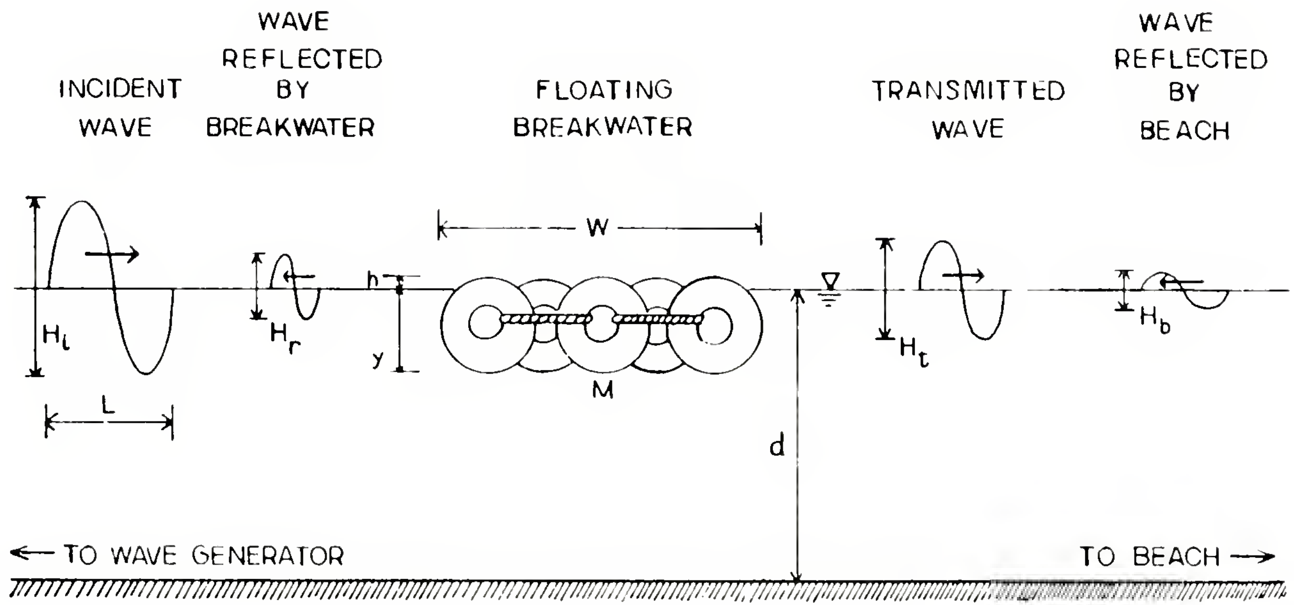

Figure 1 - Definition Sketch

W / L = non-dimensional breakwater width

H_i / L = wave steepness

y / d = relative breakwater draft

II - 3 Goodyear's Floating Tire Breakwater

The Goodyear Tire and Rubber Company has proposed and tested a modular floating tire breakwater (FTB) system (reference 5) which utilizes worn tires to provide small-harbor and marina protection. It was this FTB configuration which was used exclusively throughout the current scaling investigation. The easy-to-construct modular unit is composed of 18 individual tires tightly bundled to form a 7 feet x 6-1/2 feet x 2-1/2 feet module. A sketch of the completed unit is provided in Figure 2. Any number of these modules may then be interconnected to form the desired shape required of the particular protective structure. Flotation can be provided by naturally entrapped air in the torus shaped crown, rigid urethane, polystyrene foam, or empty half-gallon plastic bottles. When entrapped air is utilized, yearly maintenance for its replenishment is required. Similarly, removal of biofouling is necessary on an annual basis to ensure that proper buoyancy is provided. The FTB's mooring arrangement is typically provided by catenary anchor lines attached to every third module along the breakwater's length. The modules are reusable and are suited for multiple use and flexible plan forms.

In addition to the normal characteristics of a floating breakwater, this structure is especially cost effective. Estimates of up to 1/10th the cost per lineal foot of other protective structures have been

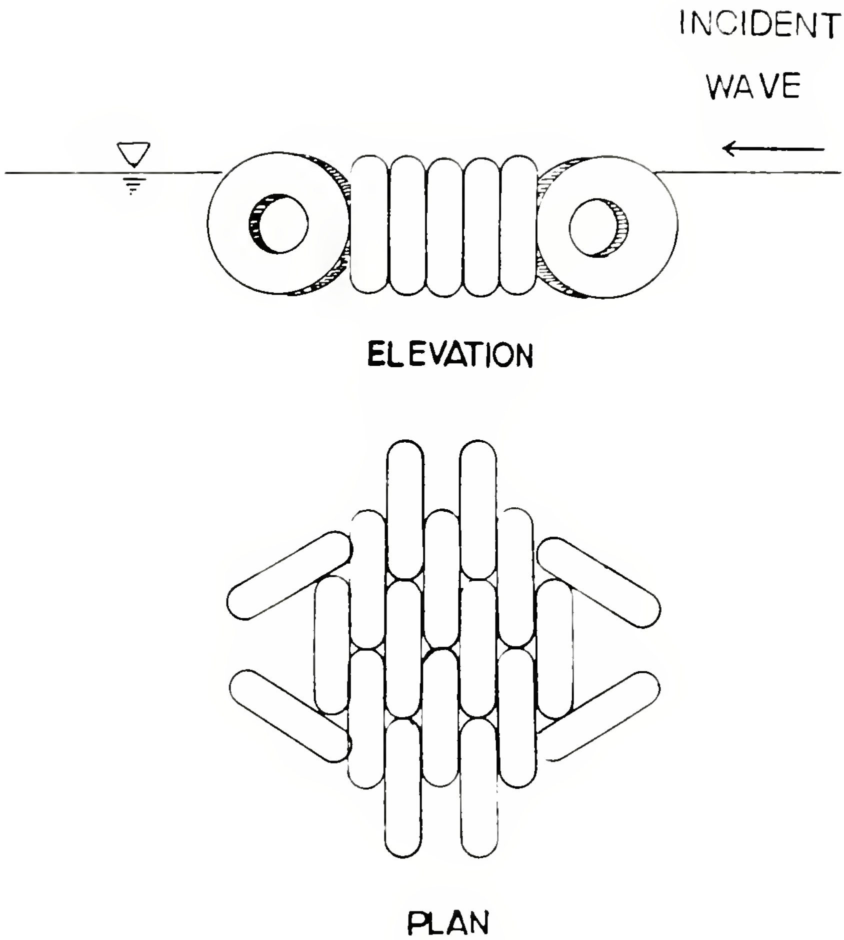

Figure 2 - Goodyear's FTB Module

quoted (reference 5). Primary expenses involve labor and anchor hardware. It should be noted, however, that initial cost is not the only criterion for floating breakwater selection. As a flexible assembly, the degree of wave protection provided by the FTB's may often be significantly less than that obtained by other floating breakwaters at comparable W / L ratios.

CHAPTER III

TEST FACILITIES AND PROCEDURES - SERIES A

The first portion of the experimental work involved appropriate scaling and design for the adaptations to both the breakwater model section and flume. Since the primary work of this investigation was to test the reliability of Froude scaling as applied to breakwater modeling, close adherence to the theory presented in Chapter II was paramount. Six-inch outside diameter rubber tires provided by the Goodyear Tire and Rubber Company were used for the Series A experiments. Their application imposed a nominal 1:5 scaling factor on all linear dimensions for this test series, since a 29-inch prototype diameter was assumed. This scaling relationship is accounted for in the paragraphs to follow which discuss the modeling apparatus, conditions, and testing procedures.

III - 1 Flume Description and Instrumentation

Series A tests were conducted in the C. W. Harris Hydraulic Laboratory's sub-floor concrete flume which is uniformly 3.5 feet deep, 4 feet wide, and 182 feet long (Figure 3). Channel water depths of 2.75 and 1.5 feet were used based on the linear scaling of CERC's test conditions of 4 and 2 meters (reference 6). Beaches are located at both ends of the flume; a 1:10 slope beach is located behind the wave generator to attenuate standing waves and a 1:16 slope beach is located at the far end of the test section which adequately absorbs transmitted wave energy. A beach reflected wave (H_b) was therefore considered inconsequential. The wave generator consists of a hinged-flap plate

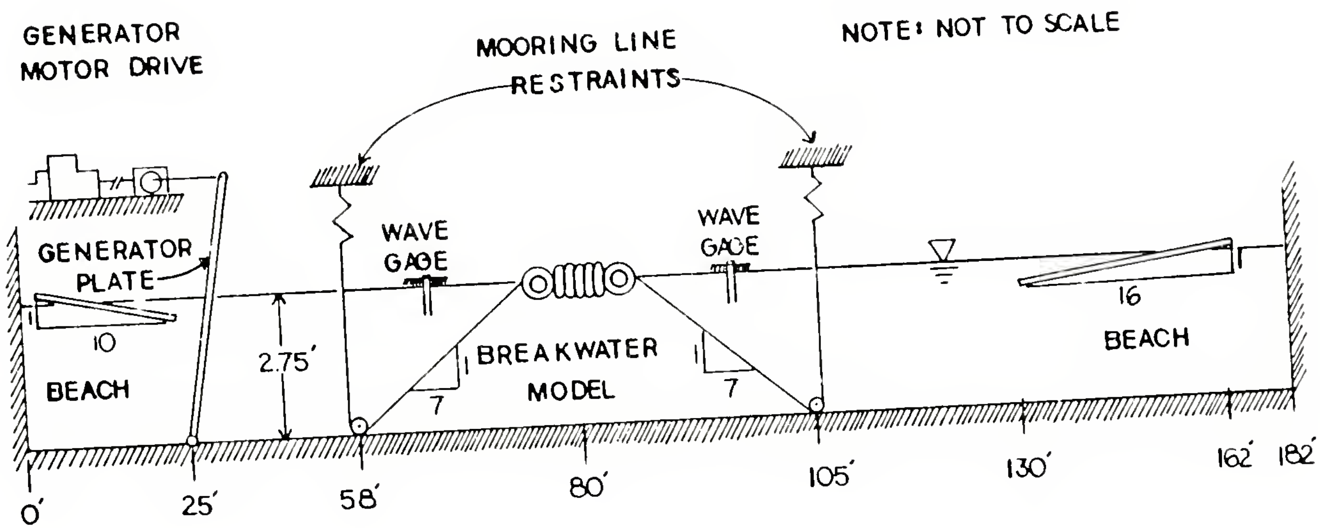

Figure 3 - Series A Flume and Experimental Apparatus

driven by a five horsepower electric motor and controlled by a Reeves Vari-Speed Moto Drive (Figure 4). This unit has continuously variable frequency and stroke over the ranges 0.6 to 1.25 Hertz and 0 to 12 inches, respectively. It produces waves of uniform height and period within approximately three wavelengths of the generator plate.

Wave conditions were measured by two fixed, resistance-wire wave gages which each form a partial arm in a Wheatstone bridge circuit. Output signals, proportional to the gage immersion depths, were amplified by two Sanborn gage amplifiers and recorded on two channels of a four channel Sanborn oscillograph.

Each gage was calibrated statically by immersing it in a vertical position to a known depth and recording the deflection of the oscillograph stylus trace. Although linear response was noted throughout the experiment, a brief test was conducted to scrutinize the effects of wave gage dynamic response. Tests were conducted using essentially vertical harmonic motions over the range 0.7 to 3.2 inches. Frequencies were varied in the range between 0.35 and 2.5 Hertz. A tendency to yield a decrease in measured amplitude was noted for increasing frequencies. Errors of less than 2% were observed at frequencies below 1.0 Hertz. At greater frequencies, errors of ±5% were observed, which supported the findings of Wiegel (reference 19). Dynamic response error was therefore considered negligible, given general wave gage resolution of 0.01 feet.

One gage fixed between the generator and test section measured incident wave height and period. The second gage, fixed approximately 10

Figure 4 - Series A Wave Generator

feet in the lee of the test station, measured the height and period of the transmitted wave. Actual gage and test section locations are included on data sheets provided in the appendices.

III - 2 Model Description

Three floating tire breakwaters, containing 6, 8, and 12 Goodyear modules respectively, were tested at the 1:5 scale. For consistency, model configurations will be referred to by the number of modules in the direction of wave advance. Since this series of tests was conducted with an incremental breakwater length (ℓ) of 2 modules parallel to wave crest, these are referred to as 3, 4, and 6 module tests.

The modules were constructed as described in Chapter II and reference 5 using 6-inch rubber tires supplied by the Goodyear Tire and Rubber Company. Number 4 nylon cord was used to tightly bind each module in a 3-2-3-2-3-2-3 arrangement. Figure 5 portrays this 1:5 Series A module and also the smaller 1:18 Series B scaled module.

Modeling apparatus analogous to CERC's prototype test section (reference 6) was required for the subsequent similitude study. Paralleling these CERC tests, breakwater modifications presented in Figure 6 included utilization of 0.25-inch diameter aluminum stabilizer bars attached to the front and rear modules to provide module alignment when secured to the anchor lines. Similarly, double loop pattern coil chain surge lines were attached along the longitudinal extremities of the test section to simulate restraint by adjacent modules. Buoyancy corrected wooden bumpers (4 inches x 4 inches x 6 inches) were fastened to the two outside tires of each module to prevent the tires from

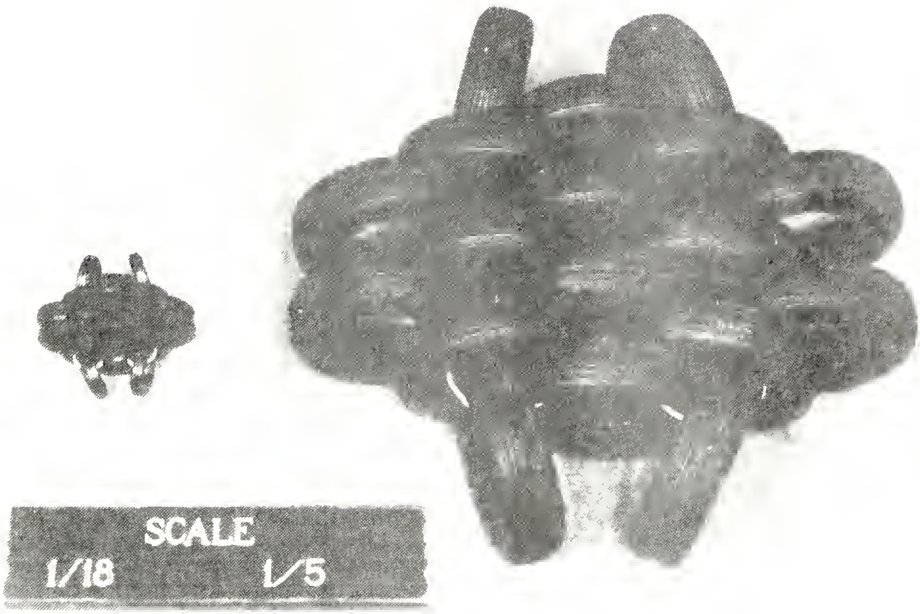

Figure 5 - Series A (1:5) and Series B (1:18) Scale Modules

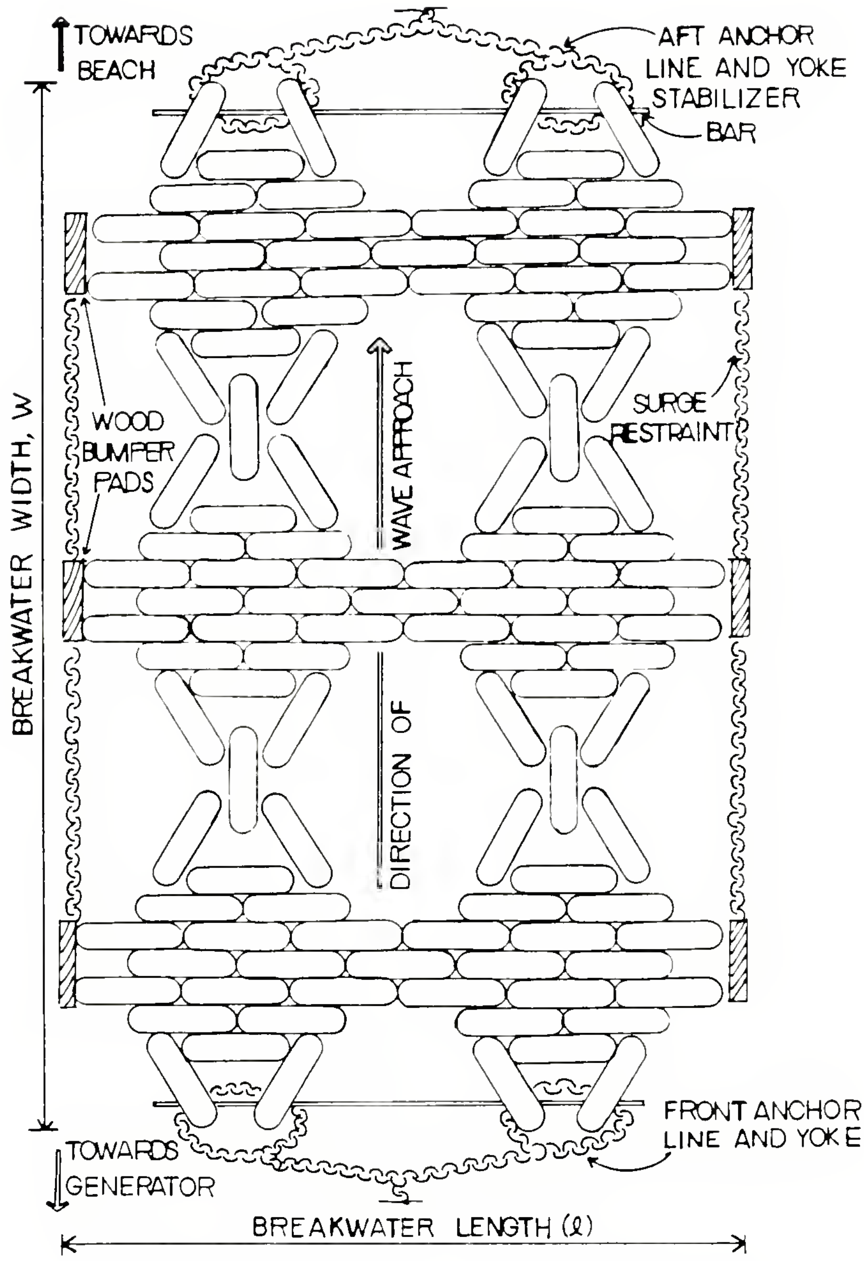

Figure 6 - Plan View of Breakwater Test Section
(3 Module Test)

scraping or binding on the tank walls.

Proper module flotation requiring only periodic replenishment was achieved via air entrapment in the tire casing crowns. An anchor line yoke similar to field installations was fabricated from No. 45 bronze sash chain and affixed to the end modules and stabilizer bars. Single number 4 nylon mooring lines were then attached to these yokes and threaded through 1-1/2 inch turning sheaves secured to the flume floor. Placement of these turning sheaves yielded roughly a 1 to 7 mooring line slope for a test depth of 2.75 feet and 1 to 10 slope for the 1.5 feet test depth. Each mooring line was attached to an overhead restraint by two pliable springs (spring constant, k=1.0 lb/in) which just maintained mooring line tension under still water conditions. This best simulated the CERC mooring line conditions which had been instrumented with load cells for the purpose of documenting anchor line forces. Figure 3 schematically displays the locations of all these model components.

III - 3 Wave Characteristics

The original intent for the test program was to reproduce scaled monochromatic waves equivalent to the prototype periods (T) ranging between 2.6 seconds to 8.3 seconds employed in the CERC tests. These periods correspond to 1.2 seconds and 3.7 seconds when 1:5 Froude scaling is applied. Upon the completion of flume calibration tests at the required linearly scaled depths of 2.75 and 1.5 feet, it was found that production of reproducible uniform and stable waves having periods greater than 1.2 seconds was not possible. Consequently, 1.2-second

waves represented the longest ones tested, while the shortest were roughly 0.8 second as limited by the generator.

Non-linear effects of these applicable waves were scrutinized in order to confirm Linear Wave Theory calculations of wavelengths (L). All stable wave combinations at both depths were compared against Le Méhauté (reference 21) and Komar (reference 11) wave theory application criteria. Whereas at both depths in the Le Méhauté realm, the waves coincided with Stoke's second and third order waves, Komar's criteria classified the majority of waves as deepwater Airy waves. Those waves indicated as second and third order Stokes waves were therefore specifically reexamined in the flume for adequacy of wavelength calculation by Airy theory. Linear distances measured between wave gages recording in-phase wave traces on the oscillograph favorably compared within ±5% with those calculated using the theory.

Accordingly, Airy theory was applied universally for data reduction as explained in Chapter V. It should be noted that the majority of test waves analyzed in Series A were characterized by depth to wavelength ratios ultimately classifying them as transitional water waves ($0.04 < d / L < 0.50$), which coincided generally with the prototype conditions modeled by CERC. These waves did, however, tend toward the deepwater end of the range. Viscous side-wall effects of the flume were also investigated by passing incident waves past two wave gages in the test section. Since no marked difference was apparent between the recorded traces, side-wall effects were determined to have negligible impact on wave conditions.

Wave parameters were varied over the maximum practical range permitted by the wave generator and flume. Their ranges are tabulated in Table 1:

Table 1

	Depth (d)	
	1.5 Feet	2.75 Feet
Period (T)	0.82-1.21 seconds	0.76-1.21 seconds
Incident Wave Height (H_i)	.02-.19 feet	.05-.63 feet
Wave Steepness (H_i/L)	.00-.03	.01-.10
d / L	.22-.53	.38-.93

III - 4 Test Procedures

The procedures used in this test consisted of: apparatus preparation, wave generator activiation, wave and breakwater monitoring, and verification through test reproducibility. For each test configuration the model was lowered into the flume and the wave gages positioned approximately 10 feet in either direction from the test section. Placement of the incident gage was especially important since its distance from the test section had to be long enough to allow for incident wave height recording before return of the breakwater's reflected wave created an irregular wave envelope oscillograph trace. Particular placement locations are noted in the data sheets presented in Appendix A. Similarly, turning sheaves, mooring line tension/slope, breakwater

draft, flume depth, and water and air temperatures were periodically checked and recorded.

Following a warm-up period and Wheatstone bridge circuit balance procedure, the wave gages were statically calibrated. The wave generator eccentricity and frequency were then adjusted to pre-determined settings and the wave plate was activated by a remote switch near the recorder. Oscillograph incident wave gage monitoring began when the established wave train first impinged on the test section. A tape advance speed of 10mm/second was used to trace several of the regular incident and transmitted wave forms or until an irregular wave trace was noted. Oscillograph speed was then immediately increased to 100mm/second so that the wave could be ultimately measured more accurately for its period. Figure 7 shows a sample oscillograph record. The wave generator and oscillograph drive were then turned off and the residual waves allowed to damp out in the flume.

During this time, values for H_i, H_t, and T were scaled from the trace and recorded on a data sheet. When values differed from those anticipated, the generator settings were readjusted to yield the desired incident wave. When the wave was deemed satisfactory the wave generator was reactivated to reproduce the test until C_t (H_t / H_i) values varied less than 5%.

The tests were continued at all successive generator settings in this manner for restrained lee configurations of 3, 4, and 6 modules in a water depth of 2.75 feet. Additionally, a 6 module configuration test was performed in 1.5 feet of water and a 3 module test was

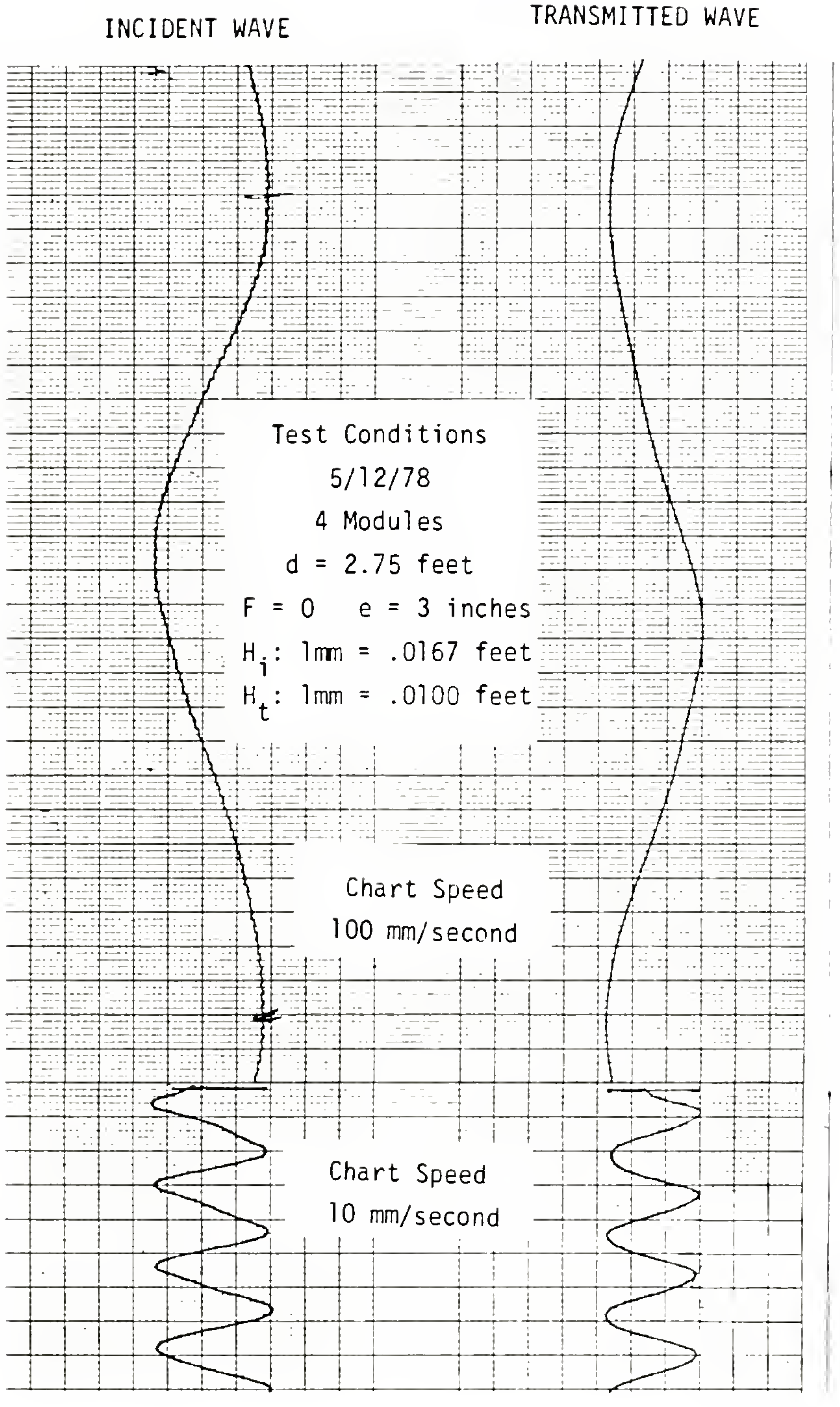

Figure 7 - Typical Oscillograph Trace

conducted at a 2.75 feet depth without a leeward mooring line to investigate unrestrained lee performance. Although not performed by CERC, 3-module tests were conducted to yield smaller non-dimensional breakwater width ratios (W / L), since the maximum generated wavelength was limited to roughly 7.5 feet. At the conclusion of each configuration test, wave gages were statically rechecked to ensure that calibration drift had not occurred. Complete tabulated values for all Series A tests are presented in Appendix A.

CHAPTER IV

TEST FACILITIES AND PROCEDURES - SERIES B

Series B experimental work essentially paralleled that of Series A, but at a reduced scale. Again, compliance with Froude scaling was mandatory for tests to be meaningful. Plastic toy tires with a 1.6 inch outside diameter were provided by the Goodyear Tire and Rubber Company for this series of tests. Correspondingly, a nominal linear scaling ratio of 1:18 was therefore applied to this series of tests as per Froude scaling rationale. Appropriate applications of this factor to the flume and breakwater section are discussed in the paragraphs to follow.

IV - 1 Flume Description and Instrumentation

Series B tests were conducted in the C. W. Harris Hydraulic Laboratory's elevated rectangular flume which is uniformly 1.5 feet deep, 2 feet wide, and 54 feet in overall length (Figure 8). Water depths of 0.67 feet and 0.33 feet were utilized based on the linear scaling of CERC's test depths of 4 and 2 meters (reference 6). The channel has transparent sidewalls from the generator to a station 30 feet away. A beach with a 1:10 slope is located at the far end of the test section which adequately absorbs transmitted wave energy. A reflected wave (H_b) was therefore considered negligible. The wave generator is a vertical-face piston type driven by a 2 horsepower electric motor and controlled by a Reeves motor drive unit. The unit has continuously variable frequency and amplitude of stroke over the ranges 0.2 to 2.0 Hertz

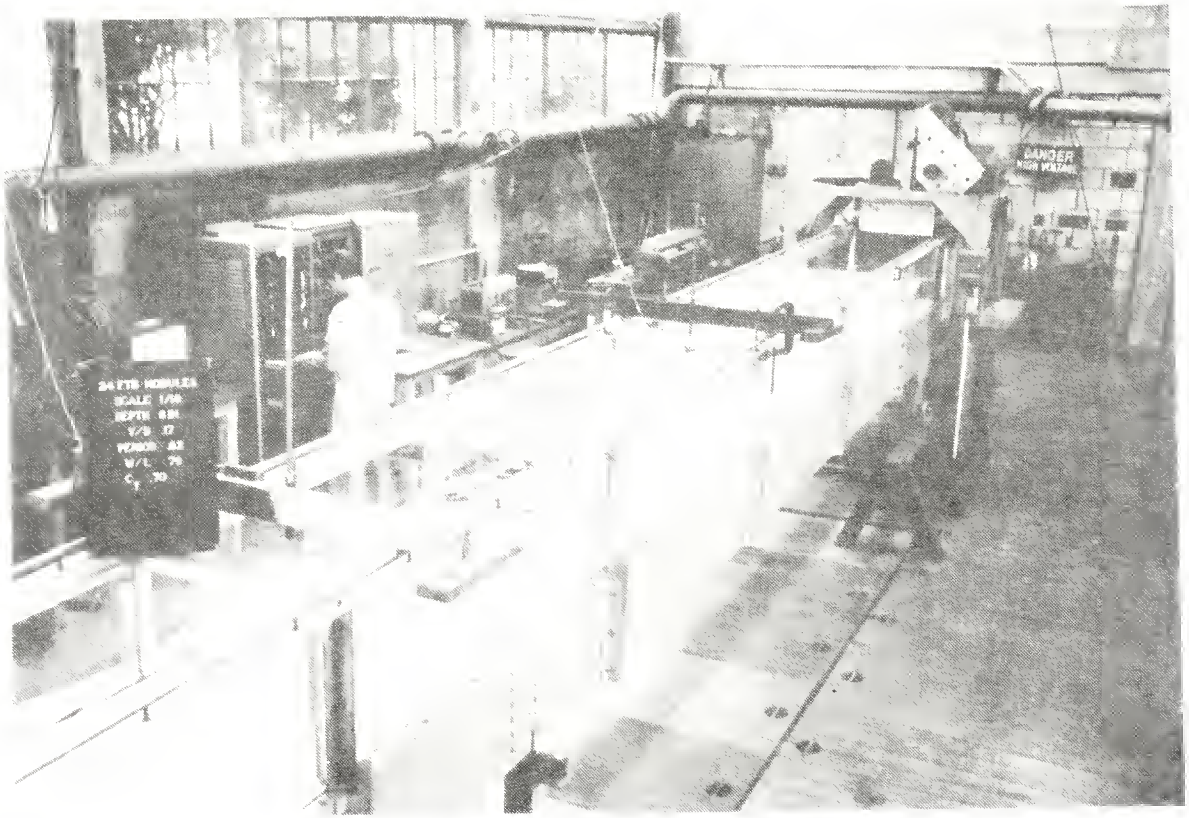

Figure 8 - Series B Flume

and 0 to 6 inches, respectively. The generator produces waves of uniform height and period within approximately four wavelengths of the generator at high frequency settings. Uniformity was observed within a wavelength at very low frequency settings.

As in the Series A tests, wave conditions were measured by the same two fixed resistance wire gages. Their criteria for placement were identical to that in the previous series with the exception that slight mounting modifications were necessary. Similarly, the same recording circuits and procedures were used for these reduced scale tests.

IV - 2 Model Description

Three floating tire breakwaters, containing 12, 16, and 24 Goodyear modules respectively were tested at the 1:18 scale. Since the flume width dictated the use of 4 modules across the tank, these again correspond with the prototype and 1:5 scale 3, 4, and 6 module tests.

The modules were constructed as described in Chapter II using the 1.6 inch plastic tires and number 18 nylon cord to tightly bind each unit. Reference is again made to Figure 5 for a relative size comparison. As in the previously described test, breakwater modifications were necessary. In this case, 0.25-inch diameter wooden stabilizer bars were attached to the front and rear modules. Wooden bumpers (2 inches x 2 inches x 1/2 inch) were again provided and fastened in an analogous manner to the modules. Number 18 nylon cord was used universally, for surge lines along the longitudinal direction of the model extremities, as well as for the mooring lines and mooring line yokes.

A plan photograph of this breakwater model is presented in Figure 9.

Turning sheaves of 1/2 inch diameter were fastened to U-braces and mounted along the flume in order to yield a 1 to 7 mooring line slope for the 0.67 foot test depth and 1 to 10 slope for the 0.33 foot depth. Each mooring line was attached to an overhead restraint by a single spring (spring constant, k = 1.0 lb/in) which just maintained mooring line tension under still water conditions. Figure 10 schematically displays the locations of these model components.

Artificial flotation was required during this test in order to achieve the proper relative breakwater depth (y / d). Since these tires were much smaller and composed of plastic they were just neutrally buoyant under an entrapped-air flotation condition. Therefore, styrofoam units (1/4 inch x 1/4 inch x 1/2 inch) were placed into the crowns of 10 tires per module. This modification then provided enough buoyancy to satisfy the scaled relative depth criterion.

IV - 3 Wave Characteristics

In order to appropriately test CERC's wave conditions at a 1:18 scale, periods of between roughly 0.6 and 2.0 seconds were required. Upon completion of flume calibration tests at the required linearly scaled depths of 0.67 and 0.33 feet, it was determined that reproducible uniform and stable waves in the range 0.50 to 3.00 seconds were attainable. Some limitations at low frequency, small amplitude waves were created due to viscous side-wall effects of the channel. Similarly, a tendency toward the generation of cnoidal waves was observed for some combinations of generator frequency and amplitude, especially at

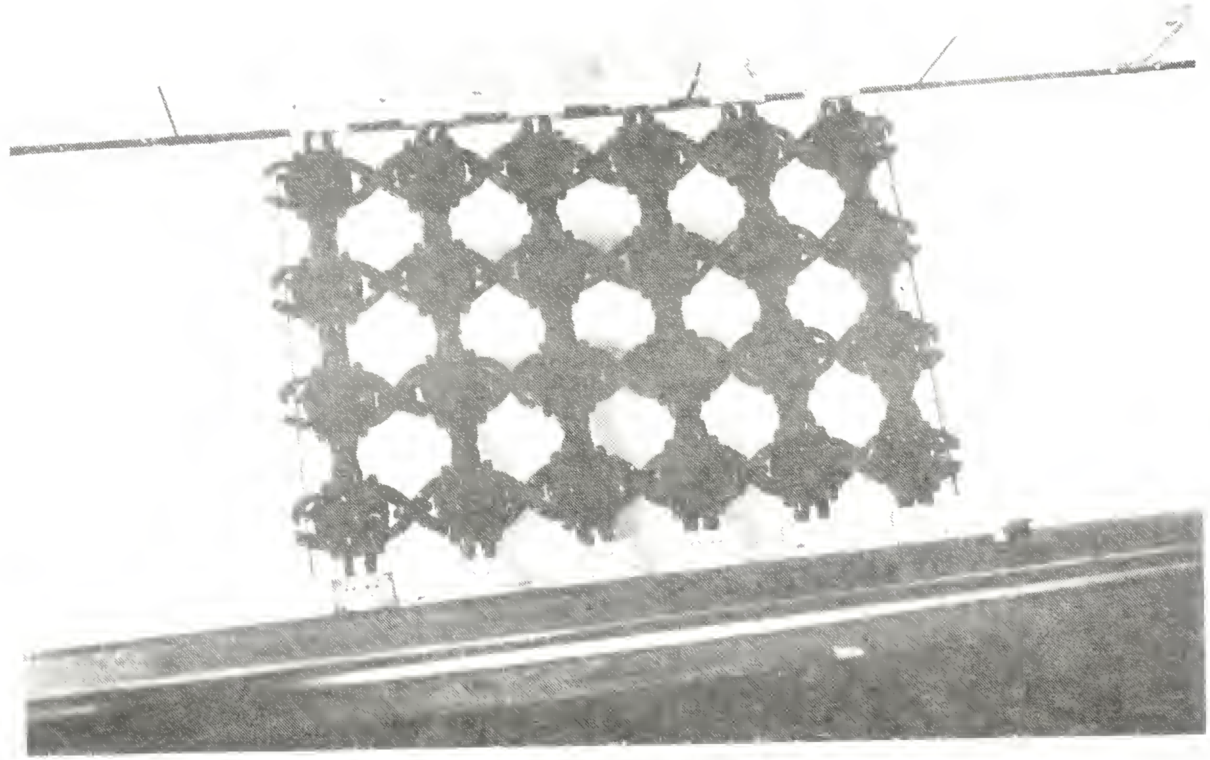

Figure 9 - Plan View of Series B (1:18) Model Test Section

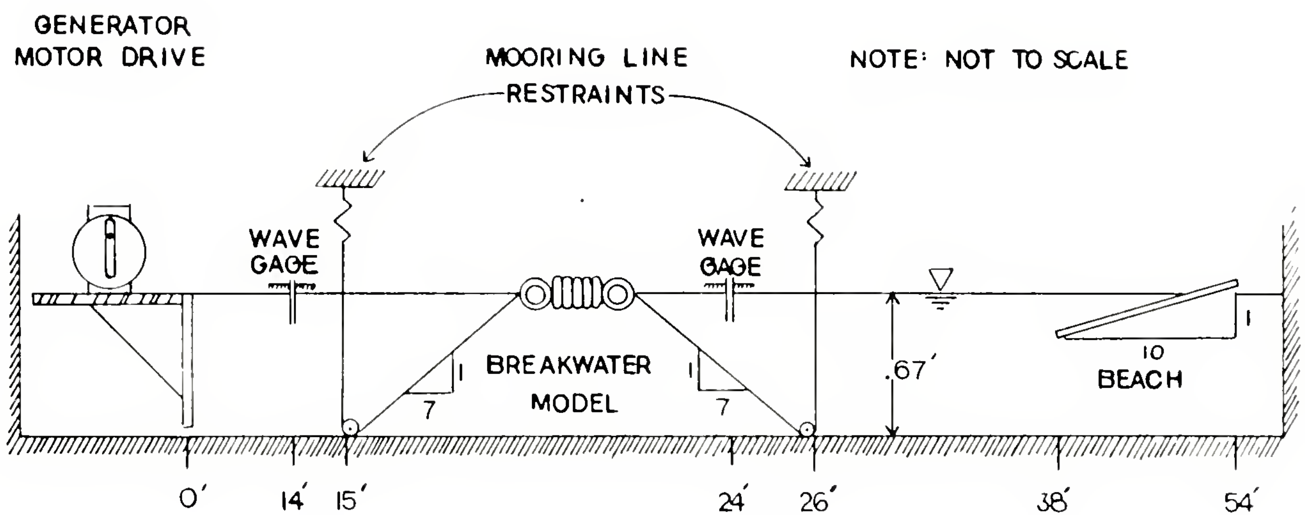

Figure 10 - Series B Flume and Experimental Apparatus

the 0.33 foot test depth. Waves exhibiting these two characteristics were accordingly eliminated from the Series B tests.

Non-linear effects of the selected waves were similarly scrutinized as in Series A to verify the applicability of Airy theory in the calculation of wavelengths (L). Le Méhauté (reference 21) and Komar (reference 11) wave theory applications were compared and the highest order waves tested. As in Series A, Airy wave theory estimations of wavelength were deemed justified. The majority of waves in the Series B test were ultimately classified as transitional water waves (0.04 < d / L < 0.50) and a very few as shallow water waves (d / L < 0.04). These wave conditions, therefore, were able to effectively model the CERC conditions.

Wave parameters were varied over the maximum practical range permitted by the wave generator and flume. Their values are listed in Table 2.

Table 2

	Depth (d)	
	0.33 Feet	0.67 Feet
Period (T)	0.53-3.00 seconds	0.52-1.52 seconds
Incident Wave Height (H_i)	.015-.110 feet	.041-.280 feet
Wave Steepness (H_i / L)	.00-.08	.01-.10
d / L	.03-.25	.10-.48

IV - 4 Test Procedures

The test procedures for this series of tests closely paralleled those of Series A. Essential steps again included: apparatus preparations, wave generator activation, wave and breakwater monitoring, and reproduction of the test results.

Due to the wave generator control location, the oscillograph recording procedures were slightly altered from Series A. Upon activation of the generator, some time (approximately 10 seconds) elapsed before the recorder was activated. Initially, tape advance speed of 100mm/second was used for subsequent wave period computation. Oscillograph drive speed was then immediately reduced to 1mm/second and stylus sensitivity increased. While the operator spent roughly 15 seconds in the evolution of turning off the wave generator, uniform wave heights were still being recorded by the two oscillograph channels. Initial values for H_i, H_t, and T were then scaled from the trace while any residual waves were allowed to damp out in the flume.

All other instrumentation calibration, application, and procedures remained the same as those conducted in Series A and previously described in Chapter III. Tests were conducted at all feasible wave generator combinations for the 3, 4, and 6 modules configurations at the 0.67 foot test depth. Figure 11 is that of a 6 module test in progress. Additionally, a 6 module test was performed in 0.33 feet of water. In order to examine unrestrained lee response a 3 module test was conducted at 0.67 feet. Complete tabulated values for all Series B tests are presented in Appendix B.

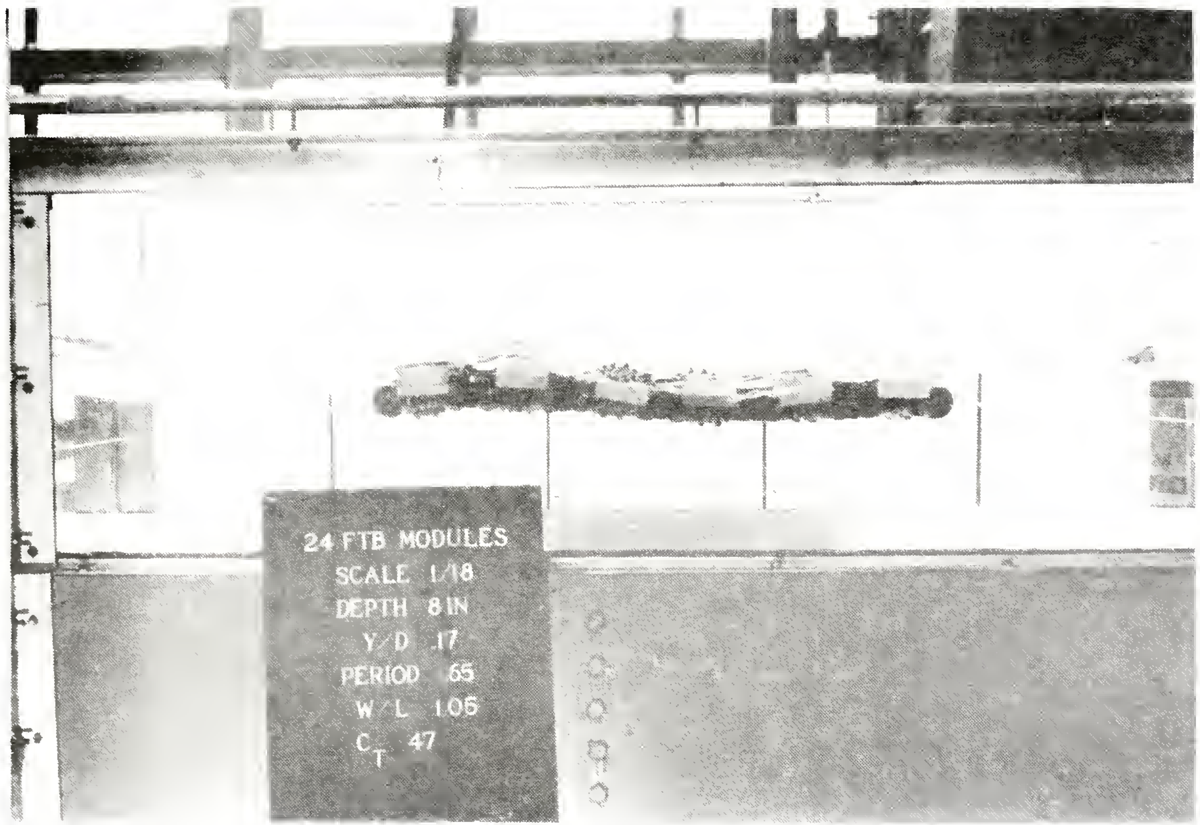

Figure 11 - Series B 6-Module Test in Operation

CHAPTER V

EXPERIMENTAL RESULTS AND ANALYSIS

The experimental data and reduction summaries for the breakwater sections tested in Series A and B are tabulated in Appendices A and B respectively. Linear wave theory was employed exclusively to calculate L_o, the deepwater wavelength:

$$L_o = \frac{gT^2}{2\pi}$$

Then, knowing water depth (d), the ratio d/L_o was transformed using tables (reference 21) to the appropriate d/L ratio which is listed on the data sheets. The ratios W/L, y/d, H_i/L, and C_t were then computed directly from the tabulated values. Experimental results for the prototype testing condition used in this study were computed at CERC in a similar fashion. It should be noted that although all data points of the present study and the CERC study are listed in the appendices and reference 6, only well grouped points were utilized in this scaling investigation. Where too few data points existed to show a trend, they were omitted from the plots presented in this chapter.

It is the purpose of this chapter to present the observable breakwater performance trends contained in the data and to note the influence of parameter adjustment on scaling effects.

V - 1 Breakwater Performance Trends

Both theoretical and physical analysis of floating breakwaters have substantiated the significance of several functional performance

relationships. One method of data investigation has utilized the Π - Theorem which can help indicate the relative importance of non-dimensional parameters. Since it is a mathematically absolute solution, the theorem has the tendency to lead researchers into hypothesizing that their models likewise have absolute validity. This is not the case as discussed in Chapter II, since the simultaneous scaling of all phenomena in physics is not possible. As such, physical intuition supported by test data when coupled with the Π - Theorem has generally concluded that, for a particular breakwater configuration:

$$C_t = f\,(W/L,\ H_i/L,\ y/d)$$

where, f is a dimensionless functional relationship.

The significance of each dimensionless parameter, as determined by several investigations, is represented by its position in this functional expression (references 6,7,9). The effect of these parameters was initially examined to ensure that proper breakwater response was being achieved. Figure 12 depicts the trends of these three dimensionless parameters as observed throughout this investigation. Values for the 6 module, Series A (1:5) test only were plotted to provide response data purely attributable to y/d and H_i/L changes. The trends are:

1 - The transmission coefficient (C_t) decreases for increasing non-dimensional breakwater width (W/L). This decline is rapid in the range of W/L values less than 2.0. C_t asymptotically approaches unity for small values of W/L, as anticipated.

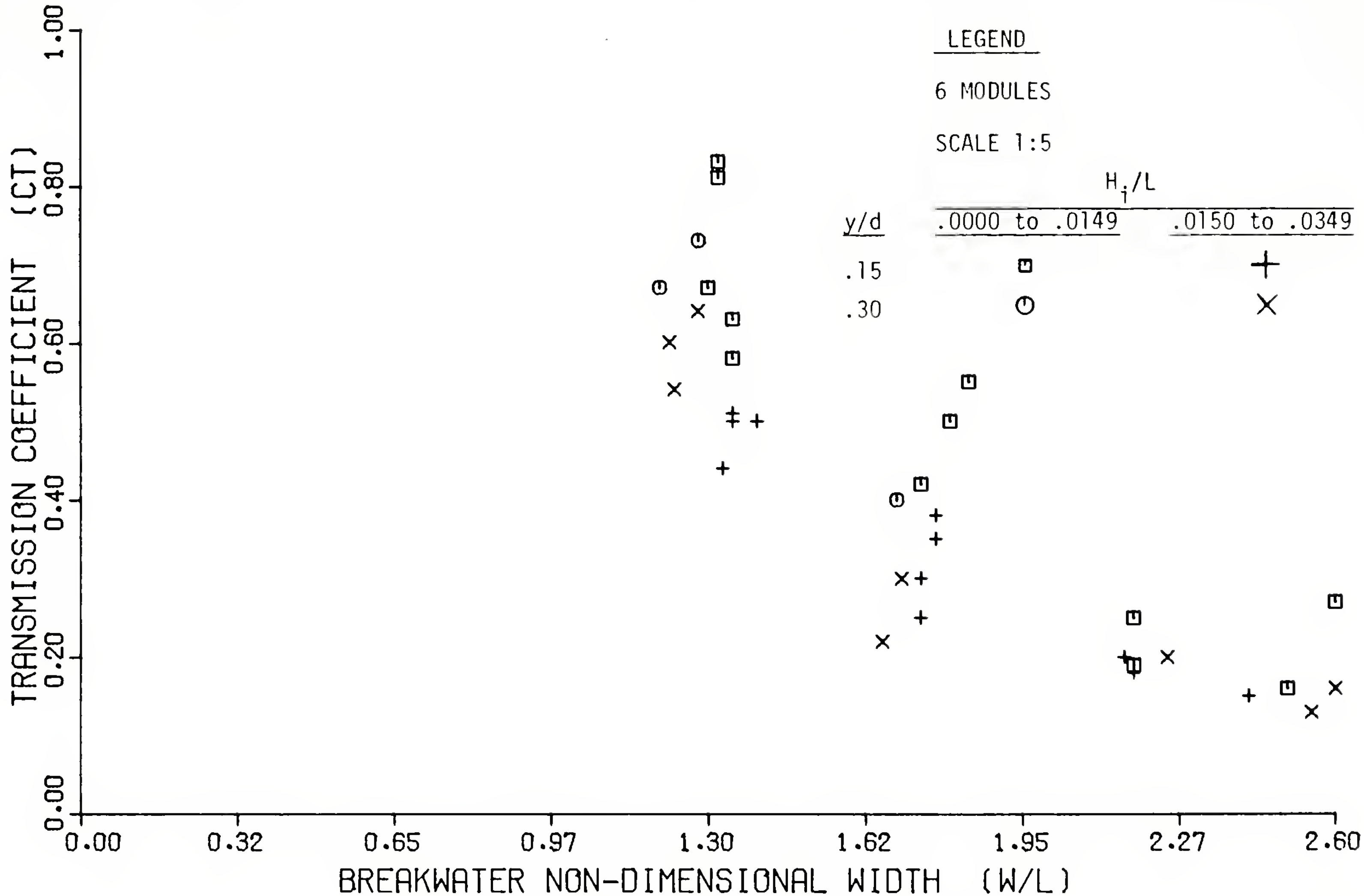

Figure 12 - Effects of y/d and H_i/L Variations

2 - The transmission coefficient decreases for increasing values of wave steepness (H_i / L).

3 - Relative breakwater depth (y / d) has only a slight tendency to effect the transmission coefficient. As y / d increases, C_t may only decrease slightly in transitional water. In a deepwater case, y / d might have a more significant effect on C_t. This, however, was not investigated in the present study since only depth (d) was varied. Trends similar to those noted above are comparable to the response of other floating breakwater configurations (reference 9).

V - 2 <u>Comparative and Scaling Effects Analysis</u>

As previously mentioned, the experimental data was scrutinized for its representative adequacy in the analysis of specific parameter alterations. Consequently, specific combinations of H_i / L , y / d, scaling ratios, module configuration and restraints were selected for comparative analysis to determine the scaling effects inherent to this investigation. For each comparison three items were investigated:

1 - The effects of the varied parameter on breakwater performance, C_t , for each independent scale.

2 - The tendency for data taken at all model scales to form a continuous and smooth performance curve at each of the varied parameters, as a check for any gross scaling errors. That is, at each value of the varied parameter, data taken at all scales was analyzed to see if it would be possible to superimpose an imaginary band over the range of points. Although not deemed appropriate for this study, further

statistical analysis could expand on this concept.

3 - Any observable trend affecting scale correlation due to the particular varied parameters. This was accomplished by comparing the change in "band widths" for the two parameter values noted in item 2. As "band width" becomes smaller the trend is toward better model scale correlation. It is re-emphasized that this particular comparison is the primary objective of this study. Each of the above mentioned relationships is discussed separately and annotated by (1), (2), and (3) in the following paragraphs.

V - 2.1 Effects of Wave Steepness (H_i / L)

Performance curves were prepared which held as constant the relative breakwater depth (y / d), the number of modules examined, while varying only wave steepness (H_i / L). These specific comparisons are presented in this section.

V - 2.1.a H_i / L : .0150-.0349 vs. .0550-.0949 , 6 Modules, y / d ≃ .15

(1) Figure 13 indicates that C_t at a specific W / L is not affected by a variation in H_i / L range at each of the 1:1 and 1:18 scales. The 1:5 scale, however, tends to show only a slight C_t responsiveness to these H_i / L comparisons. This could be interpreted to mean that H_i / L effects on C_t are more significant at higher wave steepnesses. (2) At each H_i / L considered, the composite of all three scales would, again, tend to form a reasonably continuous and smooth performance curve. A band bordered by solid lines indicates this realm for H_i / L values between .0150 and .0349. Similarly, dotted lines bound the H_i / L range

of .0550 to .0949. These boundary lines are included to clarify the comparison technique and will not be drawn on subsequent graphs.
(3) The 1:18 model has a consistently lower C_t indicating less transmission than that of the other scales. As H_i / L increases there is a trend toward better scale correlation. That is, for the steeper wave condition, variations in C_t between scales tend to reduce as depicted in the generally narrower dotted band. It should also be noted that this also occurs at increased W / L values, although for these values correlation might be attributable to the asymptotic limit of floating breakwater performance (typically C_t = 0.2).

V - 2.1.b <u>H_i / L : .0000-.0149 vs. .0150-.0349 , 6 Modules, $y / d \simeq .30$</u>

(1) Figure 14 indicates C_t response to wave steepness similar to that reported in V-2.1.a. The 1:5 scale, however, tends to indicate the anticipated decrease in C_t at greater H_i / L values. A likely explanation of this is that the Series A shorter wavelengths were closer to higher order waves than those at the other scales. (2) At each H_i / L considered, the composite of all three scales would tend to form a reasonably continuous and smooth performance curve. That is, all scales of data points are within a narrow band on the performance curve. This seems to indicate that no gross scaling effects exist. (3) It should be noted that the 1:18 scale has consistently lower C_t values than the other scales for W / L values in the range 0.4 to 0.7. No observable effect on scale correlation seems to be attributable to this H_i / L comparison, since the "bands" of data do not alter significantly between each H_i / L.

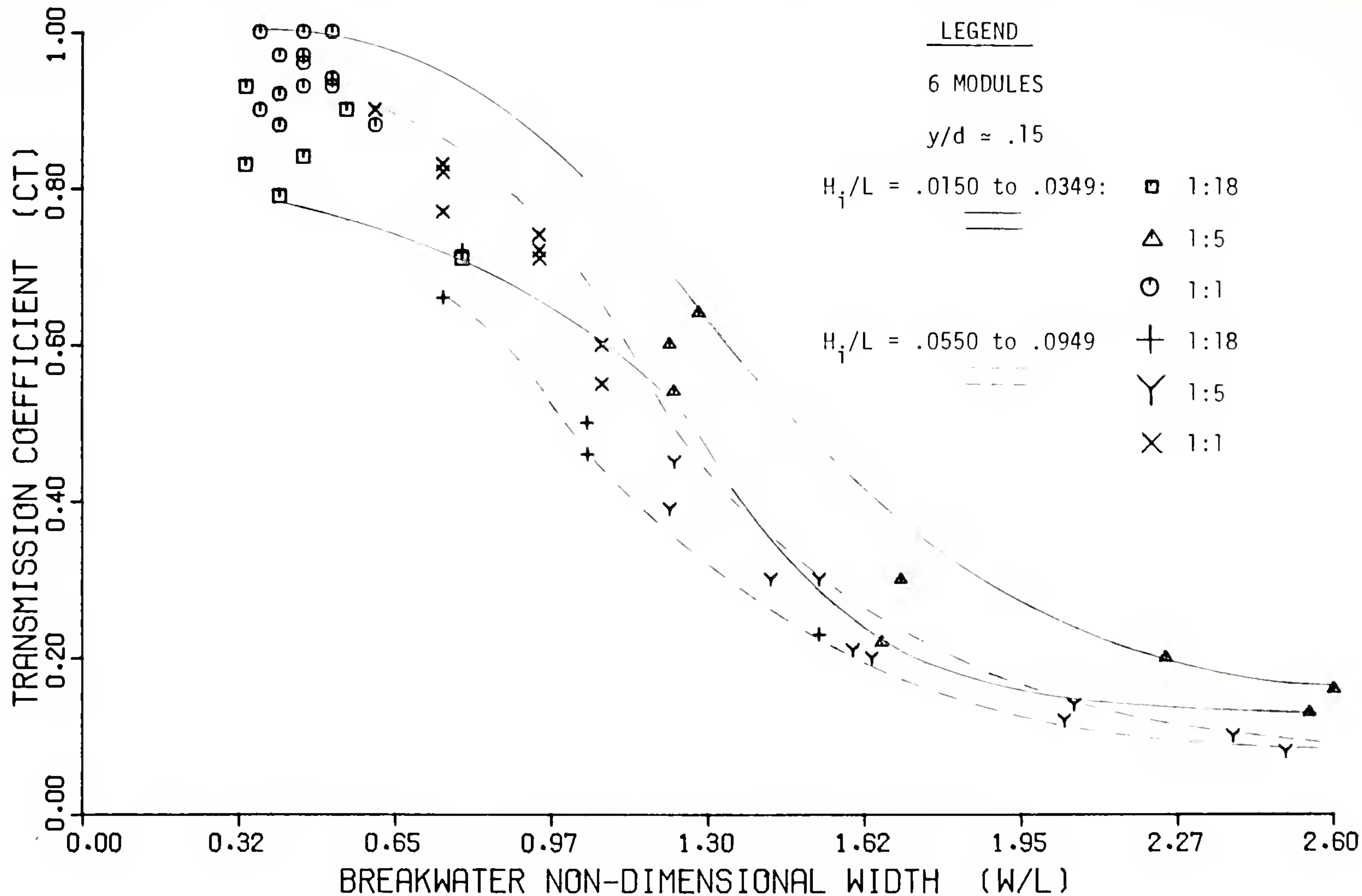

Figure 13 - Effect of H_i/L Variation (6 Modules, $y/d \approx .15$)

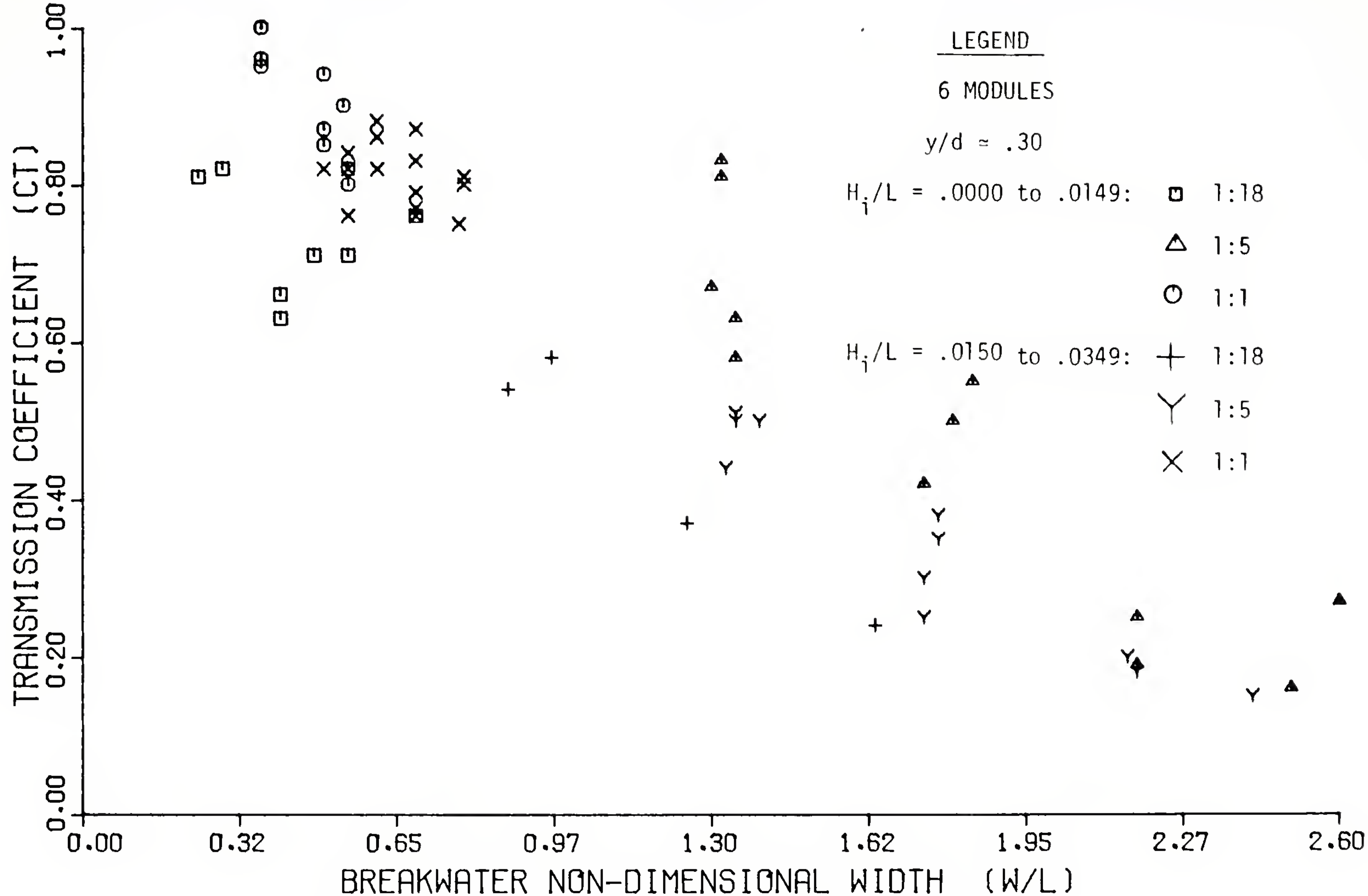

Figure 14 - Effect of H_i/L Variation (6 Modules, y/d ≈ .30)

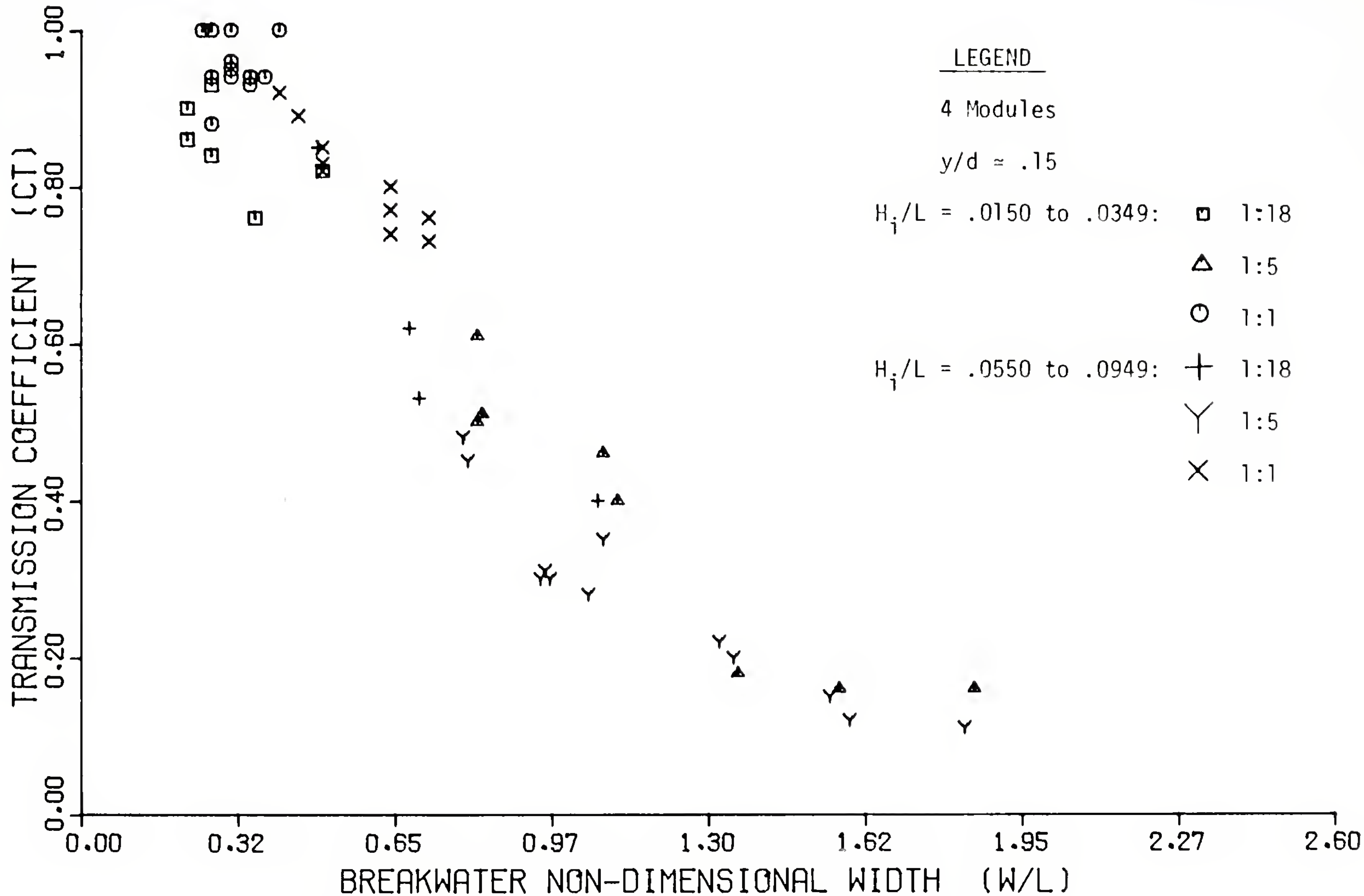

Figure 15 - Effect of H_i/L Variation (4 Modules, $y/d \approx .15$)

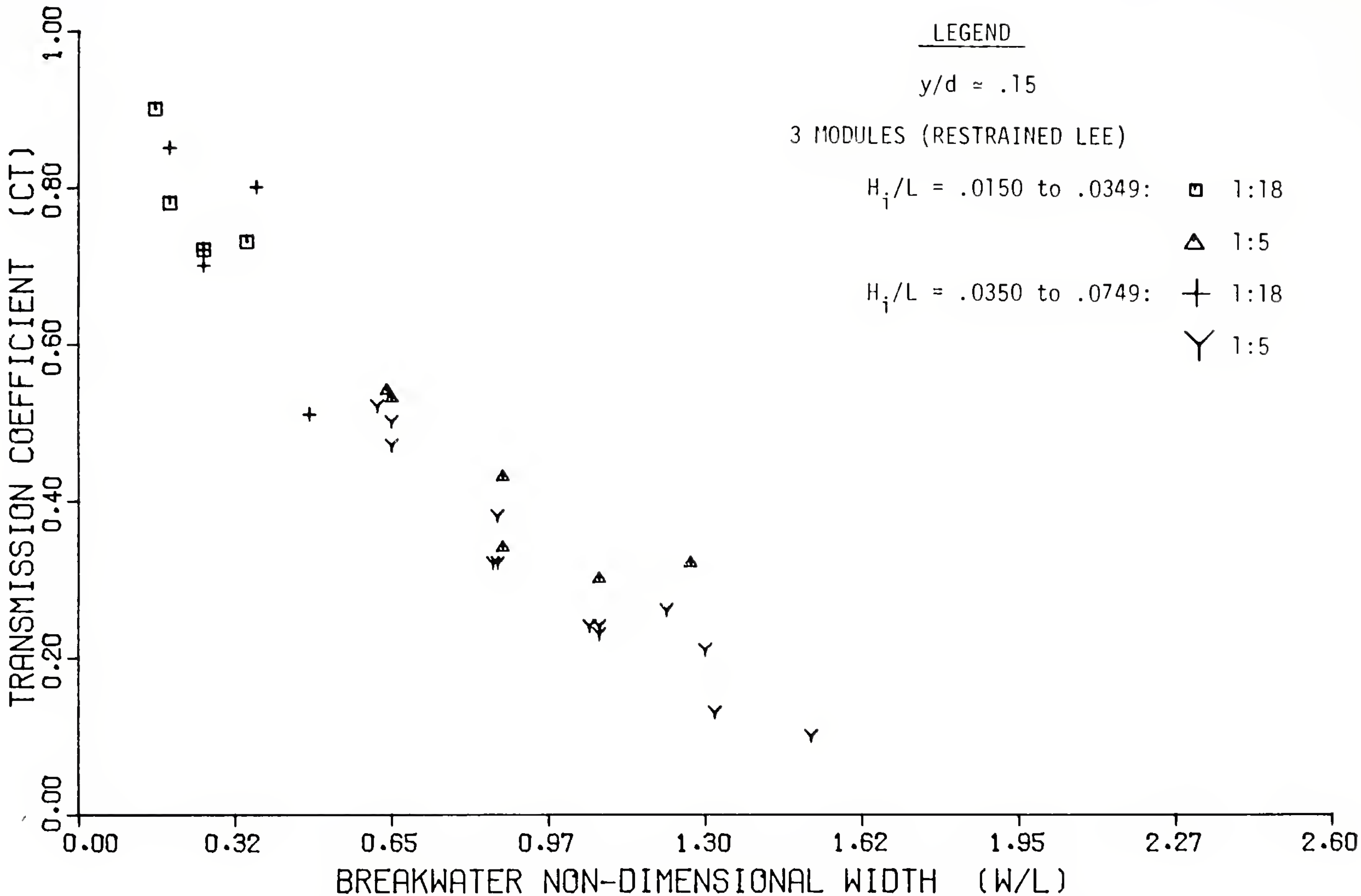

Figure 16 - Effect of H_i/L Variation (3 Restrained Modules, $y/d \approx .15$)

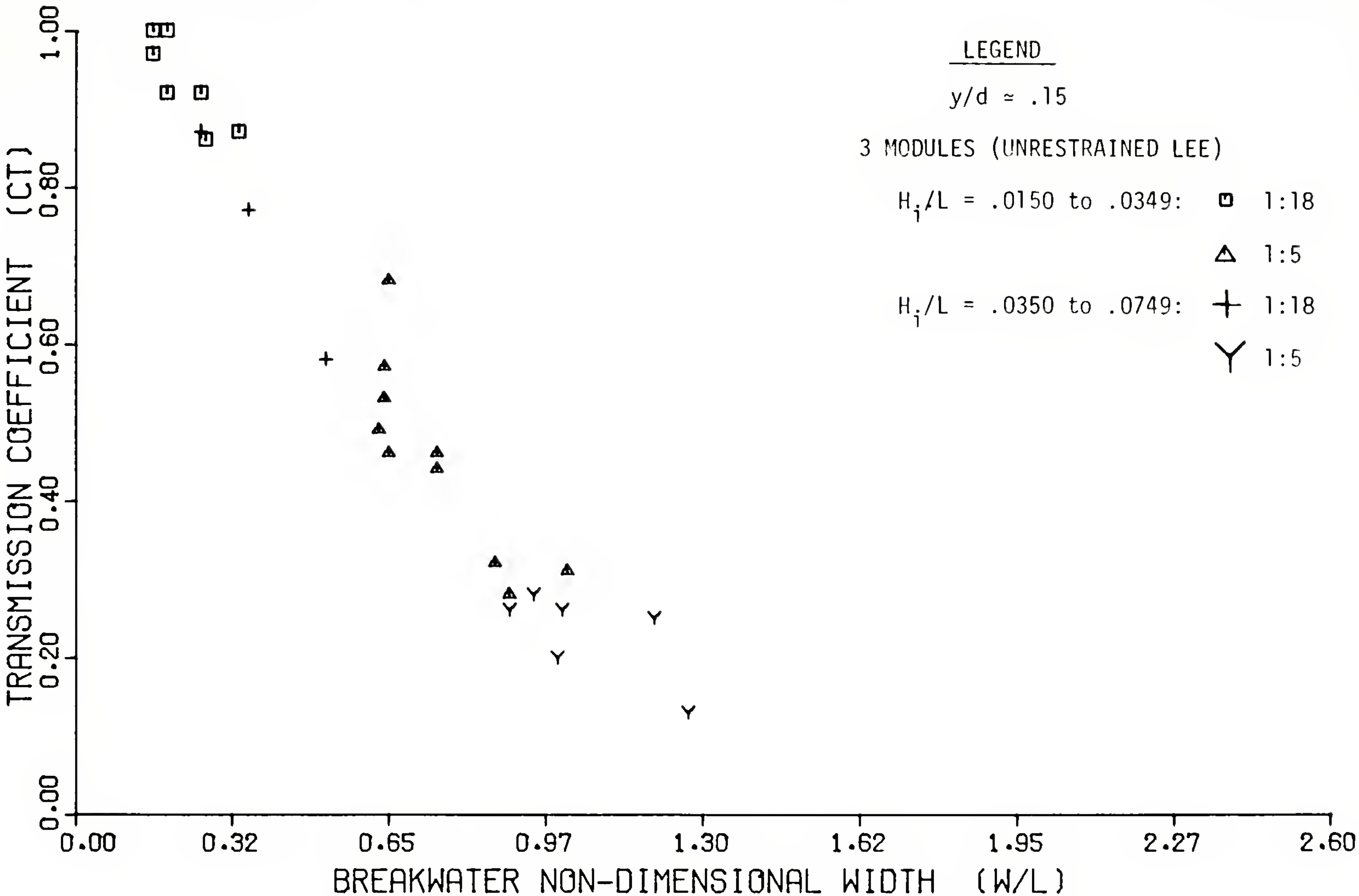

Figure 17 - Effect of H_i/L Variation (3 Unrestrained Modules, $y/d \approx .15$)

V - 2.1.c <u>H_i/L : .0150-.0349 vs. .0550-.0949 , 4 Modules, $y/d \simeq .15$</u>

(1) Figure 15 indicates C_t response to wave steepness similar to that reported in V-2.1.a. (2) Since for each H_i/L considered the composite of all three scales would tend to form a reasonably continuous and smooth performance curve, gross scaling effects are assumed to be nonexistent. (3) Again, as noted in V-2.1.a, when H_i/L increases there is a tendency toward improved scale correlation.

V - 2.1.d <u>H_i/L : .0150-.0349 vs. .0350-.0749 , 3 Modules, $y/d \simeq .15$</u>

<u>(Restrained)</u>

This comparison considers only the 1:5 and 1:18 scales. (1) Figure 16 indicates that C_t is not affected by a variation in H_i/L for either scale. (2) For each H_i/L range considered, the composite of both scales would tend to form a reasonably continuous and smooth performance curve. (3) No apparent relationship is observed between H_i/L and scaling correlation, since data for each scale are grouped at divergent W/L values.

V - 2.1.e <u>H_i/L : .0150-.0349 vs. .0350-.0749 , 3 Modules, $y/d \simeq .15$</u>

<u>(Unrestrained Lee)</u>

The 1:5 and 1:18 scales are again the only ones compared for this unrestrained lee situation. (1) Figure 17 indicates that C_t is not affected by alterations in wave steepness at each scale. (2) Gross scaling effects seem nonexistent for the same reasons as stated in previous cases. (3) There is, again, a tendency at the greater wave steepness to have improved scaling correlation.

V - 2.2 Effects of Relative Depth (y / d)

A performance curve was prepared which compared two relative depths (y / d) for the same wave steepness (H_i / L) range and module configuration.

V - 2.2.a y / d : .15 vs. .30 , 6 Modules, H_i / L = .0150-.0349

(1) Figure 18 indicates that C_t is not affected by a variation in y / d at any scale. (2) For each y / d considered, the composite of all three scales would tend to form a reasonably continuous and smooth performance curve indicating no gross scaling effects. (3) Series B (1:18) performance results indicate less transmission at that scale. There is, however, no observable change in scale correlation since data "bands" for each y / d do not differ significantly.

V - 2.3 Effects of Breakwater Width (W)

Performance curves were prepared which held as constant the relative depth (y / d) and wave steepness (H_i / L), varying only the number of breakwater modules in the direction of wave advance. These specific comparisons are presented in this section. Wave steepness of .0150 to .0349 was selected for consistency of comparison at the 3, 4, and 6 module breakwater widths. It is noted, however, that this particular wave steepness (e.g. 0.7 to 1.6 feet for L = 45 feet) is lower than that of most design waves.

V - 2.3a 6 vs. 4 Modules , y / d ≃ .15 , H_i / L = .0150-.0349

(1) Figure 19 depicts that C_t decreases at all scales as breakwater non-dimensional width (W / L) increases. Wide floating breakwaters generally attenuate waves better than narrow breakwaters. The opposite

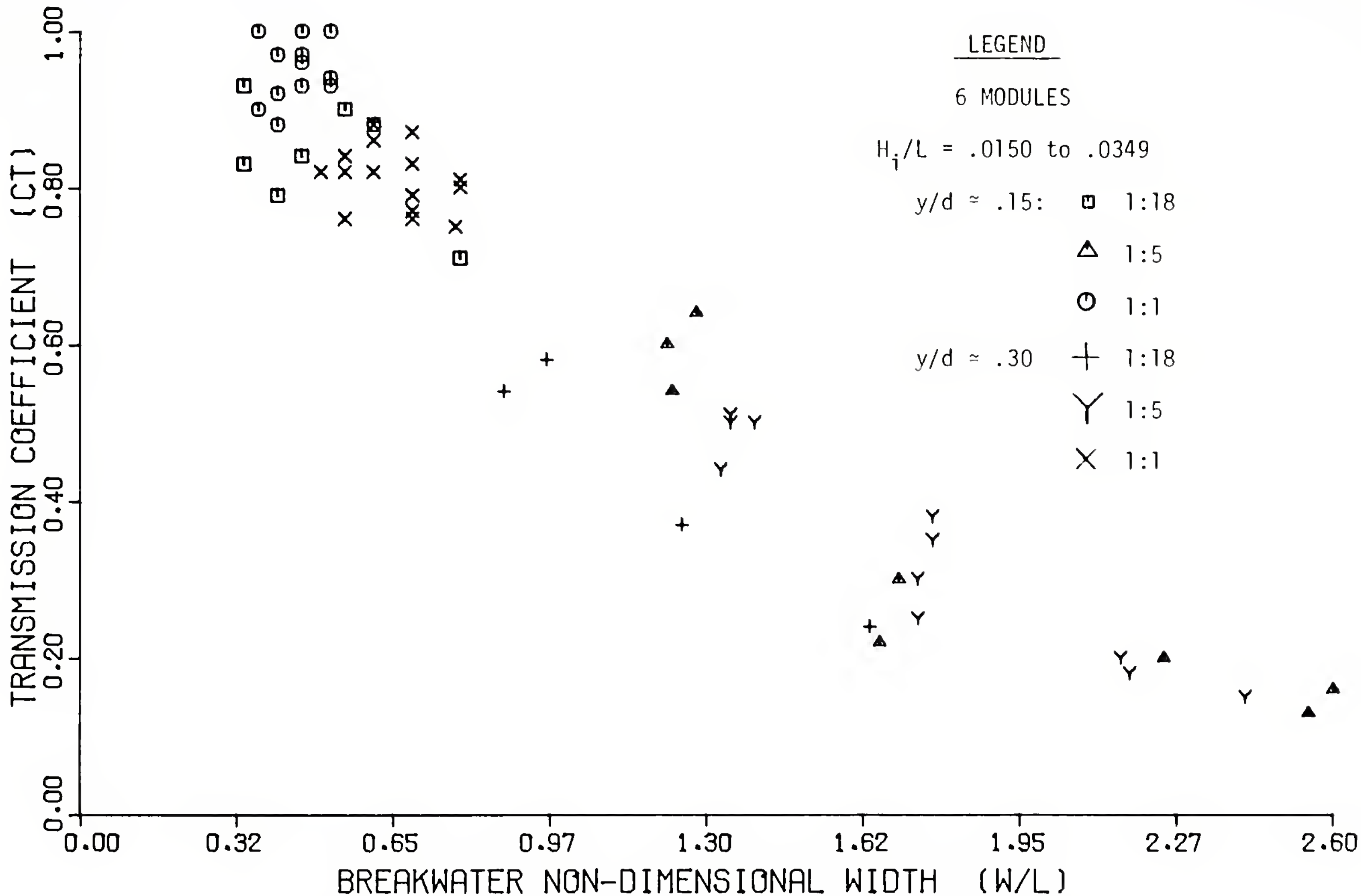

Figure 18 - Effect of y/d Variation (6 Modules, H_i/L= .0150 - .0349)

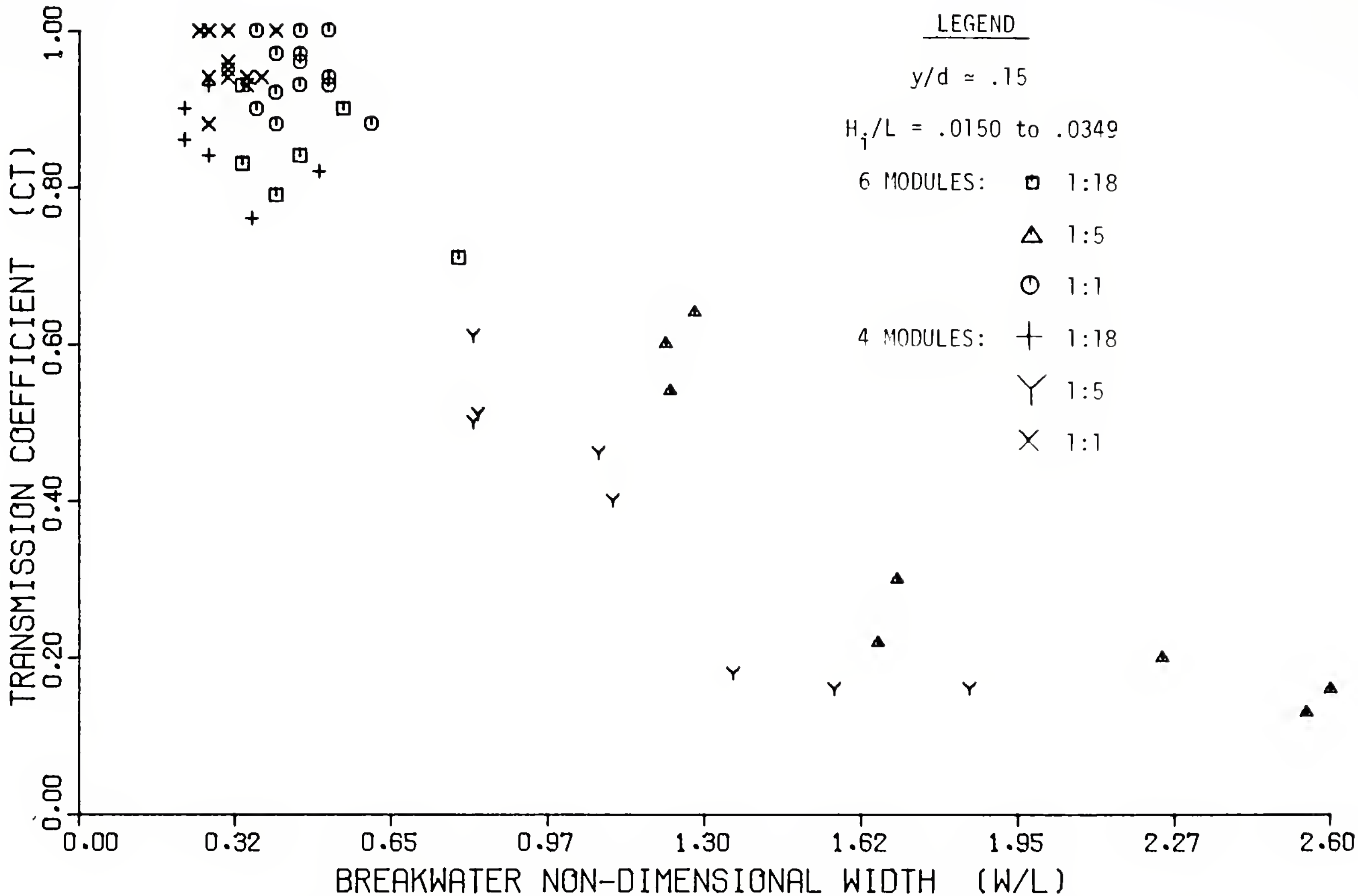

Figure 19 - Effect of 6 and 4 Module Width Variation ($y/d \simeq .15$, $H_i/L = .0150 - .0349$)

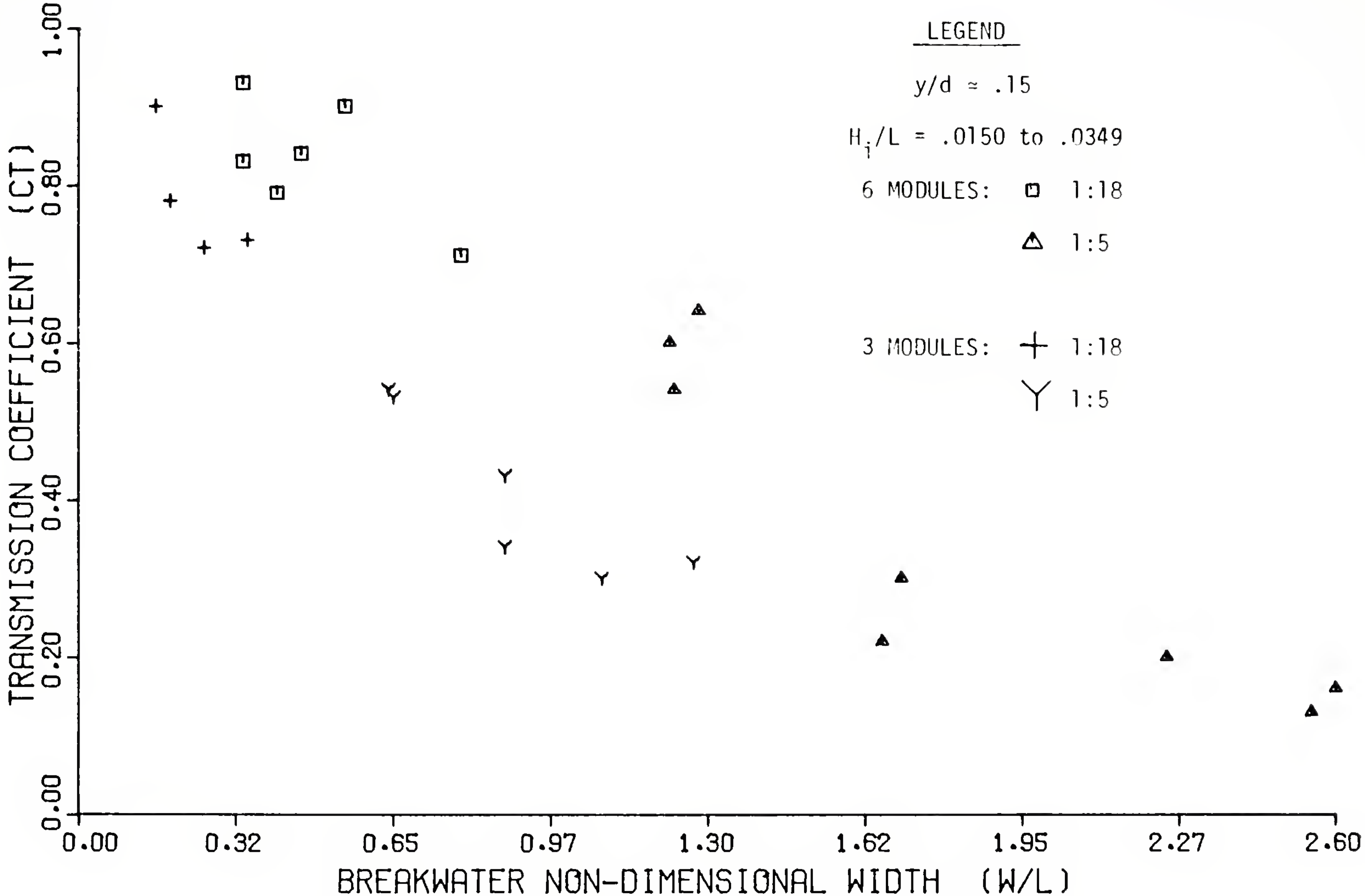

Figure 20 - Effect of 6 and 3 module Width Variation ($y/d \simeq .15$, $H_i/L = .0150 - .0349$)

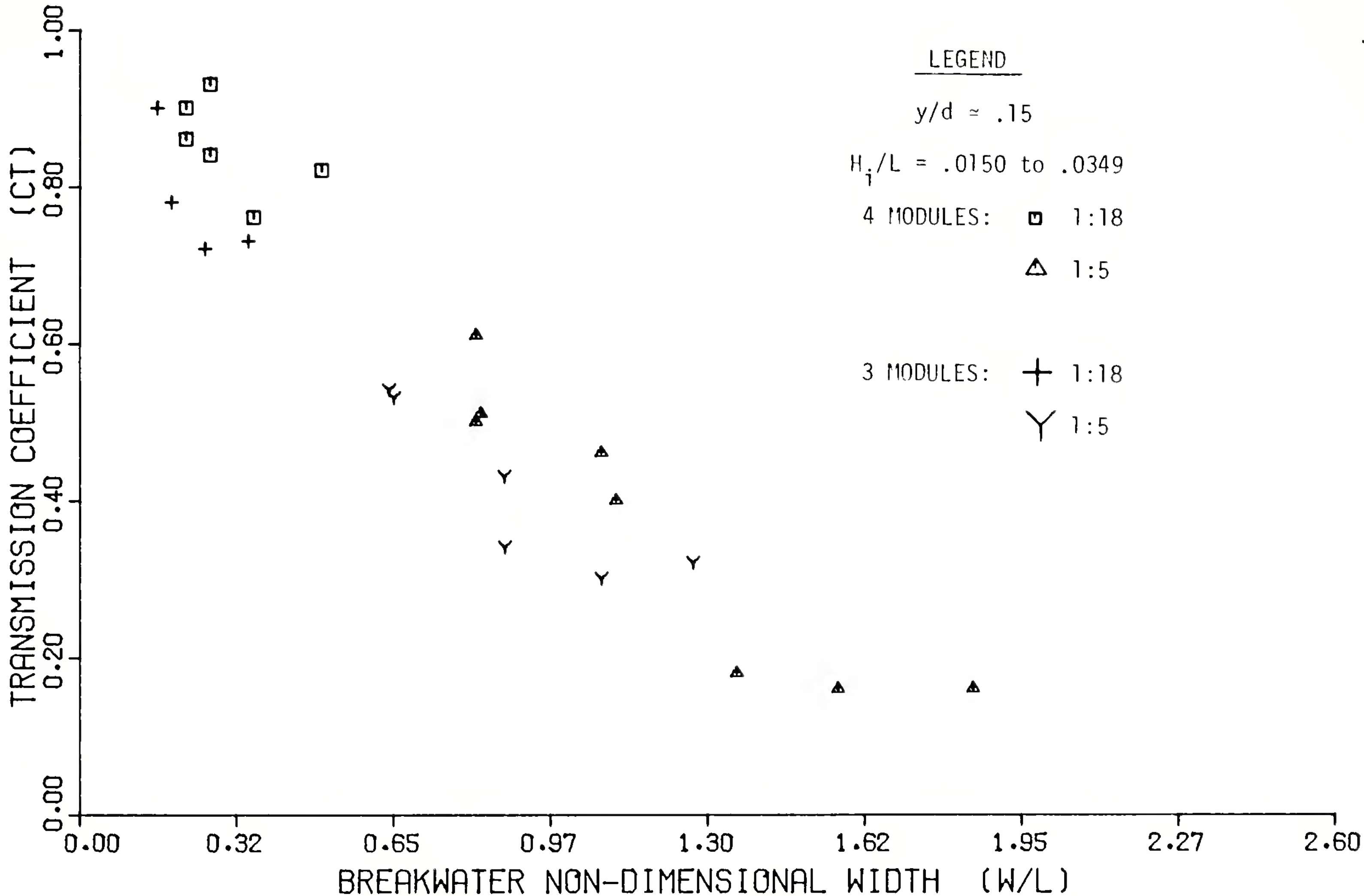

Figure 21 - Effect of 4 and 3 Module Width Variation ($y/d \approx .15$, $H_i/L = .0150 - .0349$)

was observed in both this and the CERC investigations. That is, C_t values plot lower (for a given relative width W / L) for the 4 module section than for the 6 module case. Since the 4 module section has fewer modules for the same absolute width it is less "flexible" and therefore tends to be less of a wave rider. Better attenuation could similarly be attributable to an inherent natural stiffness and dynamic response of the FTB unable to be measured in this study. Frequency response in other modes (e.g. sway, heave, and surge) would have to be studied to account for this unanticipated phenomenon. (2) At each breakwater width considered, the composite of all three scales tends to form a reasonably continuous and smooth performance band. The smallest model (1:18) again exhibits lower transmission results. (3) No trend in scale correlation seems to be attributable to variation in breakwater width in this comparison.

V - 2.3.b <u>6 vs. 3 Modules , $y / d \simeq .15$, $H_i / L = .0150-.0349$</u>

Figure 20 depicts specifically the same trends presented in V-2.3.a. Only two scales are able to be compared owing to the lack of prototype 3 module test results.

V - 2.3.c <u>4 vs. 3 Modules , $y / d \simeq .15$, $H_i / L = .0150-.0349$</u>

Figure 21 depicts generally the same trend of results as the two previous comparisons. It was observed that most attenuation was the result of mechanisms of wave breaking occurring over the first three modules. Scaling trends do not seem to be a function of breakwater width.

V - 2.4 Effects of Mooring Restraint

Performance curves were prepared which held as constant y / d, H_i / L, and W, varying simply the lee mooring situation. Restrained vs. unrestrained lee comparisons are presented in this section for scales of 1:15 and 1:18.

V - 2.4a Restrained vs. Unrestrained, 3 Modules, y / d ≃ .15, H_i / L = .0150-.0349

(1) Figure 22 indicates that C_t is not affected at the 1:5 scale by a change in restraint, although this response can be attributed to the asymptotic effects at increased W / L values where the data were obtained. At reduced W / L, where only 1:18 scale values were available, the model tends to yield consistently lower C_t values for the restrained lee case. (2) For each mooring situation, the composite of 1:5 and 1:18 scales would tend to form a reasonably continuous and smooth performance curve. (3) No change in scale correlation trends is observed as a result of mooring line alterations, since the data bands of each condition are similar.

V - 2.4.b Restrained vs. Unrestrained, 3 Modules, y / d ≃ .15, H_i / L = .0150-.0349

(1) Figure 23 indicates that C_t reduces slightly when restrained for the 1:18 model. No apparent change in performance was observable for the 1:5 model as a result of mooring line alteration. (2) Again, for each mooring situation the composite of 1:5 and 1:18 scales would tend to form a reasonably continuous and smooth performance curve. (3) No directly discernible variations in scale correlation seem to be

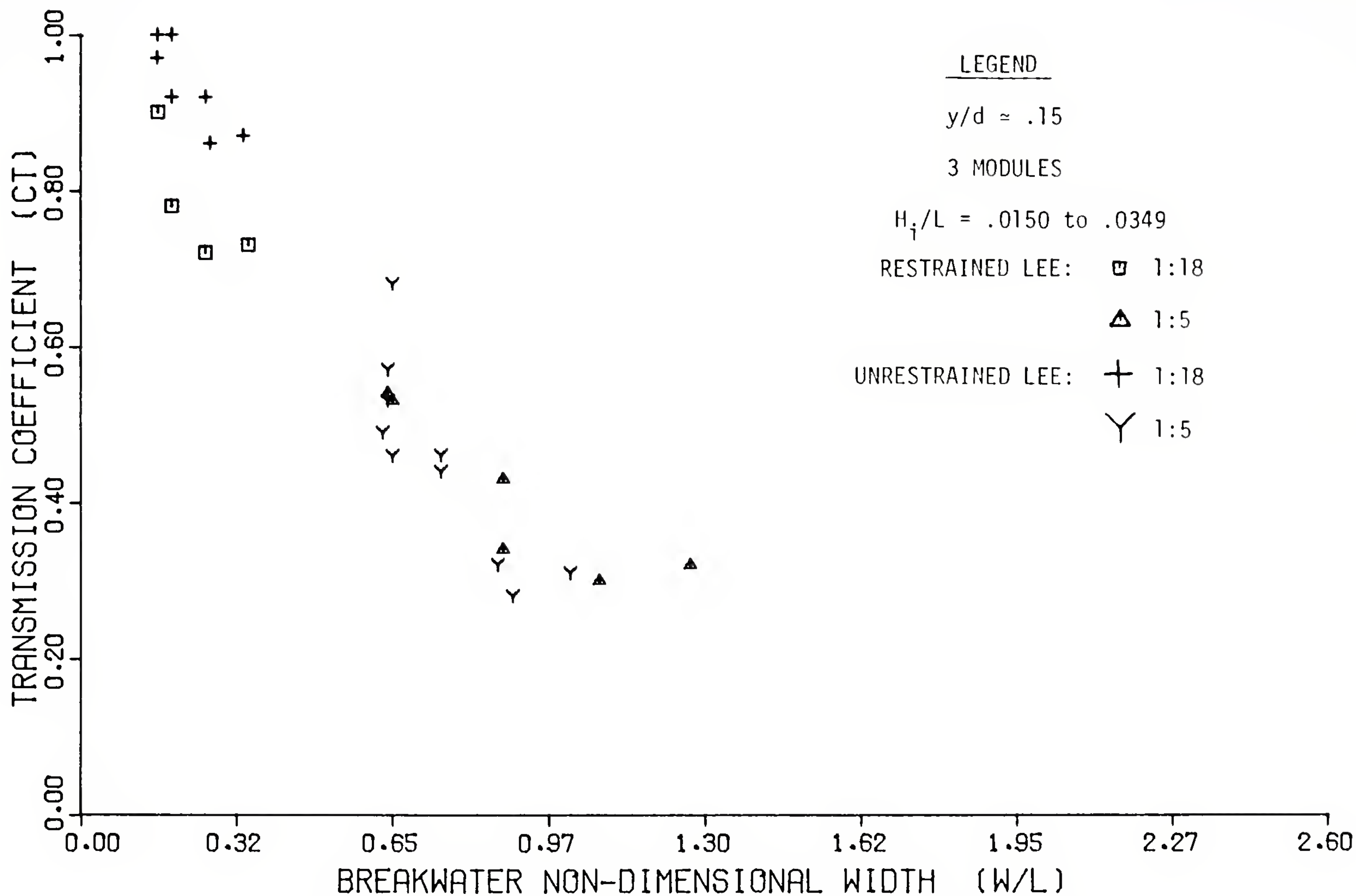

Figure 22 - Effect of Lee Restraint (3 Modules, $y/d \simeq .15$, $H_i/L = .0150 - .0349$)

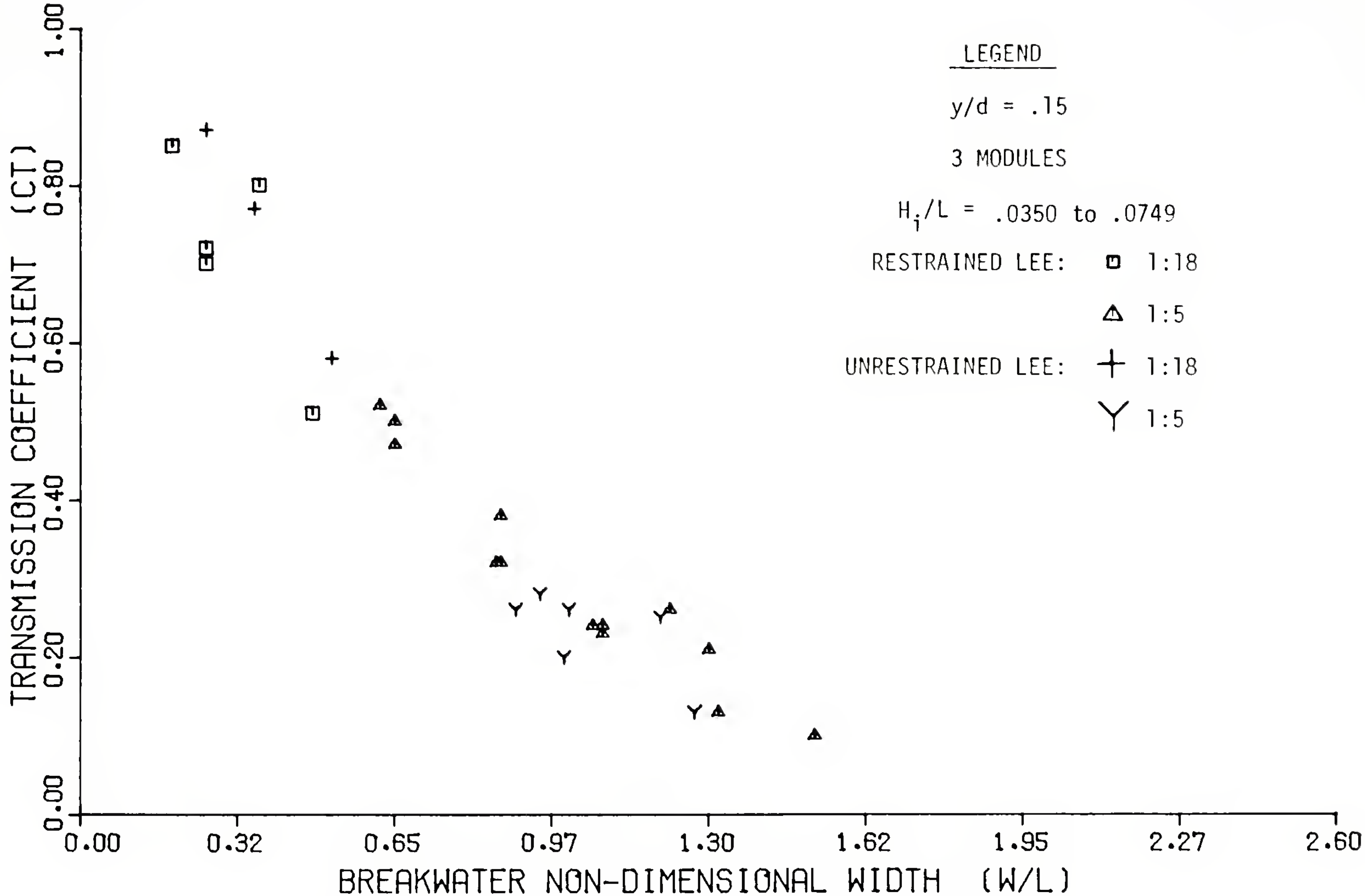

Figure 23 - Effect of Lee Restraint (3 Modules, y/d= .15, H_i/L= .0350 - .0749)

attributable to the type of mooring restraint.

V - 3 Summary of Analysis

Investigation of performance trends indicates the general validity of the 1:5 scale model, while pointing to several inadequacies in the 1:18 model. In view of the dominance of inertial and gravity forces, the Froude similitude criterion adopted for the study is substantiated. However, neglect of Reynolds similarity is consistently apparent for performance of the 1:18 scale. Figure 24 shows that the 1:18 model displayed consistently less transmission than the prototype. Viscous damping not accounted for in Froude scaling may have had an effect of increasing the 1:18 model attenuation, thereby yielding lower C_t values. The most likely explanation for this is that relative viscous effects at small scale are disproportionately larger than for the prototype, a condition contrary to Froude dynamic similitude criteria.

A brief check of the scaled Reynolds number magnitude will emphasize this point. Assuming similar fluid properties for model and prototype and recalling that $V \propto \sqrt{L}$ under Froude scaling, it can be shown that the relative Reynolds number or prototype to model ratio is:

$$\frac{\mathbb{R}_p}{\mathbb{R}_m} = \frac{V_p L_p \nu_m}{V_m L_m \nu_p} = (L_r)^{-3/2}$$

Significance of Reynolds number for each model is presented in Table 3.

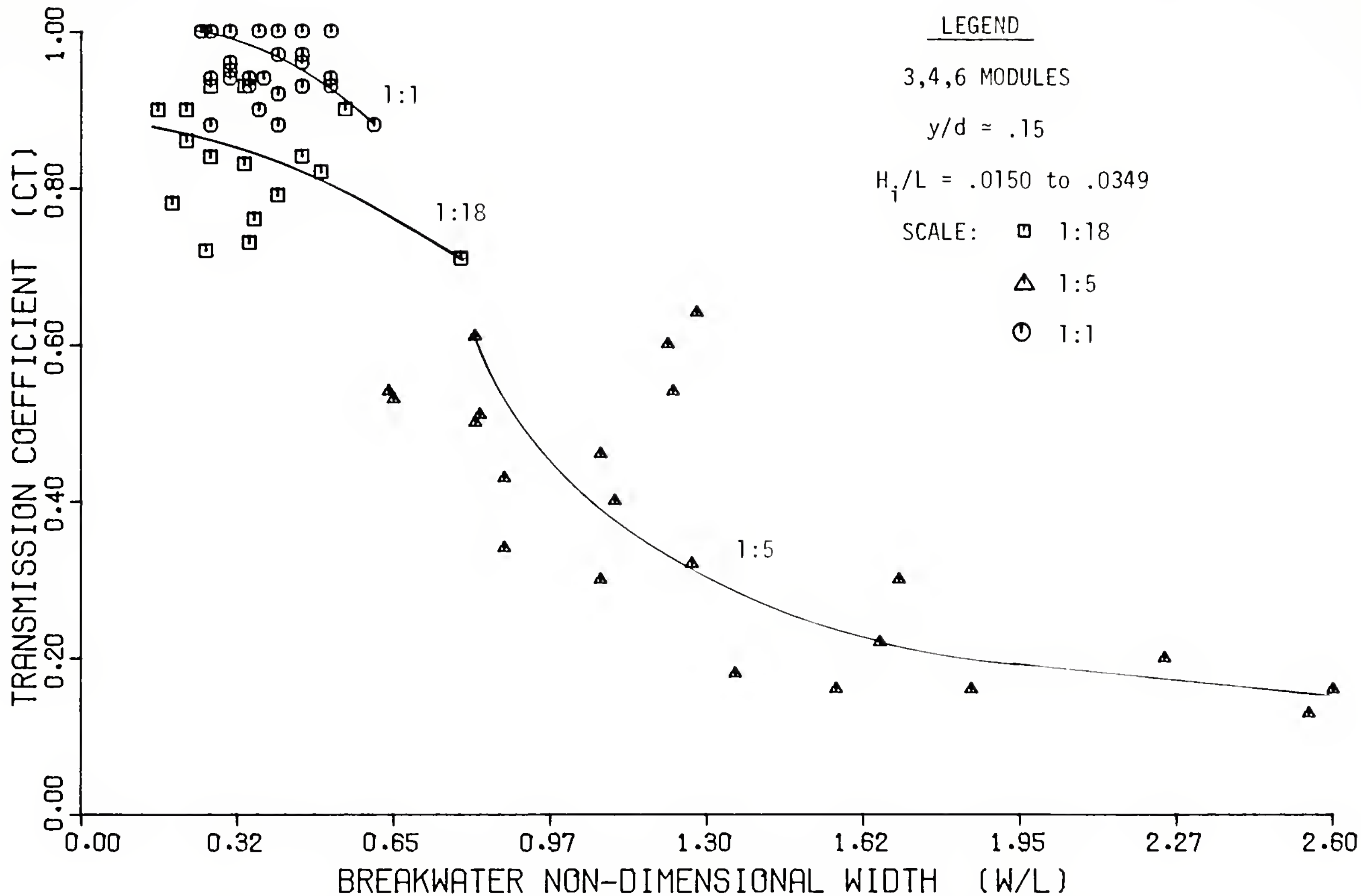

Figure 24 - Composite Performance Curve ($y/d \approx .15$, $H_i/L = .0150 - .0349$)

Table 3

Scale	L_r	Relative $\mathbb{R}$ of Unit Tested
Prototype	1/1	76.4
Series A	1/5	11.2
Series B	1/18	1.0

It can readily be seen that the importance of viscosity is altered by roughly an order of magnitude for each of the scales in question. Therefore, viscous effects at smaller scales have the effect of increasing drag. Drag coefficient and Reynolds numbers are frequently plotted on log-log paper. In this example the effect of increased relative Reynolds number is equivalent to a two cycle abscissa displacement.

These Reynolds number fluctuations could be of vital concern if the particular flow process has characteristics approaching separation. Under this condition, a very small Reynolds number alteration can correspond to a major change in drag. Increased drag on a floating breakwater would yield less transmitted energy and therefore a scaling disparity. This may have been a major cause of the 1:18 scale's inadequacy to model prototype performance.

Inadequate geometric modeling of surface roughness might similarly cause alterations in the boundary layer pressure gradient and hence induce separation at non-homologous locations. The lack of ability to adequately model turbulence is tacit to this problem.

Similar problems in accounting for simultaneous viscous and gravity effects have been historically noted in ship model testing. Due

to the apparent gravity force predominance, Froude modeling is frequently thought to govern. However, the viscous effects of hull skin friction often are of more significance. Therefore each model requires preliminary testing to determine the importance of each force accountability criterion.

Scaled elasticity effects must also be considered in a dynamic model. The 1:18 scale tires were less likely to consume incident energy through pliable tire wall deformation. Both their plastic composition and size are involved in this consideration. Conversely, their relative stiffness afforded a more rigid and therefore efficient breakwater performance. Candle (reference 4) notes that prototype transient elongations in the direction of wave advance of up to 30% have been observed under severe loading conditions. The decreased likelihood of such elongation at the 1:18 scale is another physical interpretation of the results. A more flexible model at the smaller scale therefore is needed.

Another point that might be considered is the relative amount of void space in each tire casing. Since the 1:18 model tire crowns had small portions of styrofoam placed inside, a portion of the tire voids potentially available for the disruption of orbital motion was reduced. This argument might be applied to support a situation analogous to the one observed. However, Sutko's (reference 17) research has shown that floating breakwater permeability does not seem to affect attenuation. After wrapping a previously porous net and sphere breakwater with a thin impermeable plastic sheeting, Sutko performed model attenuation

tests. Results of the tests indicated no significant change in breakwater performance. Therefore, in this FTB model study, any aberrations thought attributable to permeability are considered negligible.

Another significant trend was the observation of improved scale correlation with increased wave steepness. This can be attributed to increased breaking wave incidence at greater wave steepnesses. For these waves, the "seaward" edge of the FTB was observed to act as a "beach" upon which the incident wave would impinge and break.

Another point which briefly merits comment is the effect W / L had on scale disparity. Although scaling correlation appeared to improve with increasing non-dimensional breakwater width, this trend can be attributable to the tendency toward asymptotic performance (typically $C_t = 0.2$) at larger W / L values. Rarely are transmission coefficients less than 0.2 achieved by floating breakwaters.

CHAPTER VI

CONCLUSIONS

The conclusions of this investigation are as follows:

1 - The general validity of Froude modeling as applied to floating tire breakwaters has been shown. Results substantiate the theoretical considerations of inertial and gravity force dominance, while simultaneously confirming the intuitively physical significance of viscous effects at small scales.

2 - The 1:18 breakwater model was characterized by consistently lower wave transmission. This trend is ascribable to increased relative viscous forces at reduced scale, unaccountability of complex flow processes and an inability to scale breakwater elasticity. The 1:5 breakwater model performed adequately, providing performance data which plotted as an extrapolation of the prototype data points. Harms and Bender indicate valid model response using a 3-inch tire, yielding roughly a 1:10 scale (reference 7). It is therefore felt that the smallest scale for which floating tire breakwaters can be accurately modeled lies in the range 1:10 to 1:18.

3 - Steeper waves displayed a tendency to reduce scaling disparity. Steeper waves were observed to primarily exhibit breaking and orbital motion interruption attenuation mechanisms. As such, the relative significance of viscosity at smaller scales and its effect on energy transmission was reduced.

4 - Scaling disparity displayed an apparent tendency to reduce at increasing breakwater non-dimensional widths (W / L). This was deduced

to be a function of the limiting asymptotic performance level (approximately C_t = 0.2) for larger values of W/L.

5 - Transmission coefficient (C_t) has been shown to be a function of (in decreasing order of importance) breakwater non-dimensional width (W/L), wave steepness (H_i/L), and relative depth (y/d) for each of the three scales investigated. Incident wave height attenuation was primarily attributable to orbital motion degradation and breaking wave phenomenon.

6 - Restraint of breakwater lee for long wavelengths (L) displayed a tendency to reduce incident wave transmission when compared with an unrestrained lee condition. This response was attributable to the increased relative breakwater rigidity and surge restriction. Transmission performance was generally independent of mooring techniques for steeper incident waves. This response is ascribable to the large relative significance of the breaking mechanism observed at the most seaward modules.

7 - A need is seen for future investigation into breakwater elastic response at small scales. Model tire alteration or looser module binding techniques might provide the means for more accurate model response.

8 - Less energy transmission was exhibited where fewer modules provided the same absolute width. This response should be investigated by monitoring the FTB's heave and surge characteristics. Such a study would provide an excellent opportunity to perform tests at the 1:5 scale and then to check the results against prototype response.

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APPENDIX A

SERIES A DATA TABULATION

Date: 5/13/78	Tested by: W. Nelson	
Series: A	# Modules: 6	Water depth (d): 1.5 ft
Breakwater width (w): 8.8 ft	Seaward edge: Sta 52 ft	
Water temperature: 14.5° C	Air temperature: 16° C	
Mooring line turning sheaves:	#1 - Sta 33 ft	#2 - Sta 80 ft
y/d: 0.28		
Wave gages: H_i - Sta 44.5 ft	Attenuation X5	1 mm = .0073 ft
H_t - Sta 68 ft	Attenuation X5	1 mm = .0073 ft

e (in)	F	T (sec)	H_i (ft)	H_t (ft)	C_t	d/L	L (ft)	H_i/L	w/L
6.0	.00	1.18	.18	.09	.52	.23	6.52	.03	1.35
6.0	.00	1.18	.19	.09	.51	.23	6.52	.03	1.35
5.0	.00	1.20	.17	.07	.43	.22	6.82	.02	1.30
5.0	.00	1.19	.16	.07	.45	.23	6.52	.02	1.35
4.0	.00	1.14	.14	.07	.53	.25	6.00	.02	1.46
4.0	.00	1.18	.14	.07	.47	.23	6.52	.02	1.35
4.0	.25	1.01	.15	.04	.24	.30	5.00	.03	1.77
4.0	.25	1.02	.15	.04	.25	.29	5.17	.03	1.71
3.0	.00	1.19	.10	.05	.50	.23	6.52	.02	1.35
3.0	.00	1.18	.10	.05	.50	.23	6.52	.02	1.36
3.0	.25	1.02	.11	.04	.33	.29	5.17	.02	1.71
3.0	.25	1.00	.12	.03	.28	.30	5.00	.02	1.77
2.5	.00	1.19	.09	.04	.50	.23	6.52	.01	1.35
2.5	.00	1.19	.09	.05	.58	.23	6.52	.01	1.35
2.5	.25	1.01	.09	.04	.38	.30	5.00	.02	1.77
2.5	.25	1.01	.10	.03	.32	.30	5.00	.02	1.77
2.5	.50	.92	.14	.02	.16	.36	4.17	.03	2.12
2.5	.50	.90	.15	.02	.15	.36	4.05	.04	2.18
2.0	.00	1.20	.07	.04	.67	.22	6.82	.01	1.30
2.0	.00	1.20	.07	.04	.67	.22	6.82	.01	1.30
2.0	.25	1.00	.09	.03	.38	.30	5.00	.02	1.77
2.0	.25	1.00	.09	.03	.38	.30	5.00	.02	1.77
2.0	.50	.90	.10	.02	.18	.37	4.05	.02	2.18
2.0	.50	.90	.10	.02	.18	.37	4.05	.02	2.18
2.0	.75	.85	.09	.01	.17	.41	3.70	.02	2.39
2.0	.75	.84	.09	.01	.13	.42	3.61	.02	2.45
1.5	.00	1.19	.05	.03	.65	.23	6.52	.01	1.35
1.5	.00	1.17	.05	.03	.61	.23	6.52	.01	1.35
1.5	.25	1.02	.06	.02	.42	.29	5.17	.01	1.71
1.5	.25	1.00	.06	.02	.42	.30	5.00	.01	1.77
1.5	.50	.90	.07	.01	.20	.37	4.05	.02	2.18
1.5	.50	.91	.09	.01	.19	.36	4.17	.02	2.12

Continuation

Series: A # Modules: 6 Water depth (d): 1.5 ft

e (in)	F	T (sec)	H_i (ft)	H_t (ft)	C_t	d/L	L (ft)	H_i/L	w/L
1.5	.75	.93	.07	.01	.21	.35	4.29	.01	2.06
1.5	.75	.85	.07	.01	.19	.41	3.70	.02	2.39
1.0	.00	1.19	.03	.02	.80	.23	6.52	.00	1.35
1.0	.00	1.21	.03	.03	.82	.22	6.82	.00	1.30
1.0	.25	1.01	.03	.02	.50	.30	5.00	.01	1.77
1.0	.25	.99	.03	.02	.50	.31	4.84	.01	1.82
1.0	.50	.90	.05	.01	.19	.37	4.05	.01	2.18
1.0	.50	.90	.05	.01	.18	.37	4.05	.01	2.18
1.0	.75	.83	.04	.01	.21	.53	3.53	.01	3.50
1.0	.75	.83	.05	.01	.13	.43	3.53	.01	2.50
.50	.00	1.20	.02	.02	.86	.22	6.82	.00	1.30
.50	.00	1.19	.02	.02	.79	.23	6.52	.00	1.35
.50	.25	1.00	.02	.01	.53	.30	5.00	.00	1.77
.50	.25	.98	.02	.01	.57	.32	4.60	.00	1.88
.50	.50	.90	.03	.01	.27	.36	4.05	.01	2.18
.50	.50	.90	.03	.01	.20	.37	4.05	.01	2.18
.50	.75	.80	.02	.01	.25	.46	3.28	.01	2.69
.50	.75	.82	.02	.01	.29	.44	3.44	.01	2.57

Date: 5/13/78		Tested by: W. Nelson
Series: A	# Modules: 6	Water depth (d): 2.75 ft
Breakwater width (w): 8.8 ft		Seaward edge: Sta 52 ft
Water temperature: 15° C		Air temperature: 17° C
Mooring line turning sheaves:	#1 - Sta 33 ft	#2 - Sta 80 ft
	y/d: 0.15	
Wave gages: H_i - Sta 44.5 ft	Attenuation X10	1 mm = .0155 ft
H_t - Sta 68 ft	Attenuation X 10	1 mm = .0101 ft

e (in)	F	T (sec)	H_i (ft)	H_t (ft)	C_t	d/L	L (ft)	H_i/L	w/L
6.0	.00	1.20	.48	.19	.39	.38	6.24	.07	1.22
6.0	.00	1.20	.49	.19	.39	.38	6.24	.07	1.22
6.0	.12	1.05	.54	.17	.31	.49	5.64	.10	1.57
6.0	.12	1.08	.55	.15	.27	.46	5.97	.09	1.48
5.0	.00	1.20	.40	.19	.46	.38	6.24	.06	1.22
5.0	.00	1.19	.41	.18	.44	.39	6.05	.06	1.25
5.0	.12	1.10	.46	.14	.30	.44	6.20	.07	1.42
5.0	.12	1.09	.46	.14	.30	.45	6.09	.09	1.45
4.0	.00	1.19	.33	.16	.47	.39	6.05	.05	1.25
4.0	.00	1.20	.32	.16	.48	.38	7.24	.04	1.22
4.0	.25	1.05	.34	.07	.20	.49	5.64	.06	1.57
4.0	.25	1.03	.35	.08	.22	.51	5.43	.06	1.63
3.0	.00	1.19	.26	.13	.50	.39	6.05	.04	1.25
3.0	.00	1.19	.26	.13	.50	.39	6.05	.04	1.25
3.0	.25	1.02	.38	.06	.21	.52	5.33	.05	1.66
3.0	.25	1.03	.30	.06	.20	.51	5.43	.06	1.63
2.5	.00	1.20	.22	.12	.54	.38	7.24	.03	1.22
2.5	.00	1.19	.22	.12	.54	.39	7.05	.03	1.25
2.5	.25	1.03	.25	.05	.20	.51	5.43	.04	1.63
2.5	.25	1.04	.25	.05	.20	.50	5.54	.05	1.59
2.5	.50	.92	.28	.04	.14	.63	4.33	.06	2.04
2.5	.50	.91	.28	.04	.14	.65	4.24	.07	2.08
2.0	.00	1.20	.17	.11	.63	.38	7.24	.02	1.22
2.0	.00	1.19	.18	.11	.58	.29	7.05	.03	1.25
2.0	.25	1.02	.22	.04	.20	.52	5.33	.04	1.66
2.0	.25	1.00	.20	.05	.24	.54	5.12	.04	1.72
2.0	.50	.92	.25	.03	.12	.63	4.33	.06	2.04
2.0	.50	.92	.24	.03	.12	.63	4.33	.06	2.04
2.0	.75	.85	.29	.02	.08	.74	3.70	.08	2.39
2.0	.75	.85	.28	.03	.11	.74	3.70	.08	2.39

Continuation

Series: A   # Modules: 6   Water depth (d): 2.75 ft

e (in)	F	T (sec)	H_i (ft)	H_t (ft)	C_t	d/L	L (ft)	H_i/L	w/L
1.5	.00	1.17	.13	.09	.76	.40	6.88	.02	1.28
1.5	.00	1.17	.14	.09	.73	.40	6.88	.02	1.28
1.5	.25	1.02	.15	.03	.22	.52	5.33	.03	1.66
1.5	.25	1.02	.15	.03	.22	.52	5.33	.03	1.66
1.5	.50	.90	.20	.03	.16	.66	4.15	.05	2.13
1.5	.50	.92	.21	.03	.14	.63	4.33	.05	2.04
1.5	.75	.82	.22	.01	.07	.80	3.44	.06	2.47
1.5	.75	..84	.19	.02	.09	.76	3.61	.05	2.45
1.5	1.0	.79	.17	.02	.12	.86	3.20	.05	2.76
1.5	1.0	.77	.17	.01	.09	.91	3.04	.06	2.90
1.0	.00	1.26	.10	.07	.68	.35	7.86	.01	1.12
1.0	.00	1.18	.10	.07	.66	.40	6.88	.01	1.28
1.0	.25	1.02	.12	.04	.32	.52	5.33	.02	1.66
1.0	.25	1.00	.12	.03	.27	.54	5.12	.02	1.72
1.0	.50	..89	.13	.02	.16	.68	4.06	.03	2.17
1.0	.50	.90	.15	.02	.17	.66	4.15	.04	2.13
1.0	.75	.84	.14	.01	.11	.76	3.61	.04	2.45
1.0	.75	.84	.15	.02	.12	.76	3.61	.04	2.45
1.0	1.0	.79	.13	.01	.07	.86	3.20	.04	2.76
1.0	1.0	.79	.13	.01	.09	.86	3.20	.04	2.76
.50	.00	1.18	.06	.04	.72	.40	6.88	.01	1.28
.50	.00	1.17	.06	.04	.74	.40	6.88	.01	1.28
.50	.25	1.01	.07	.03	.40	.53	5.22	.01	1.69
.50	.25	1.01	.07	.03	.40	.53	5.22	.01	1.69
.50	.50	.90	.08	.02	.20	.66	4.15	.02	2.13
.50	.50	.87	.09	.02	.18	.71	3.88	.02	2.28
.50	.75	.82	.08	.01	.13	.80	3.55	.02	2.57
.50	.75	.84	.08	.01	.12	.76	3.61	.02	2.45
.50	1.0	.80	.07	.01	.17	.84	3.28	.02	2.69
.50	1.0	.78	.07	.01	.16	.88	3.12	.05	2.83

Date:5/12/78		Tested by: W. Nelson
Series: A	# Modules: 4	Water depth (d): 2.75 ft
Breakwater width (w): 5.7 ft		Seaward edge: Sta 54.5 ft
Water temperature: 14 ° C		Air temperature: 16° C
Mooring line turning sheaves:	#1 - Sta 33 ft	#2 - Sta 80 ft
	y/d: 0.15	
Wave gages:	H_i - Sta 46 ft	Attenuation X10 1 mm = .0167
	H_t - Sta 68 ft	Attenuation X10 1 mm = .0100

e (in)	F	T (sec)	H_i (ft)	H_t (ft)	C_t	d/L	L (ft)	H_i/L	w/L
6.0	.00	1.20	.52	.24	.46	.38	7.24	.07	.78
6.0	.00	1.18	.55	.24	.44	.40	6.88	.08	.82
6.0	.12	1.09	.57	.17	.30	.45	6.08	.09	.93
6.0	.12	1.09	.58	.18	.31	.47	5.86	.10	.97
6.0	.12	1.09	.58	.18	.21	.47	5.86	.10	.97
5.0	.00	1.19	.45	.21	.47	.30	7.05	.06	.80
5.0	.00	1.20	.44	.22	.50	.38	7.24	.06	.78
5.0	.12	1.09	.48	.15	.31	.46	5.97	.08	.95
5.0	.12	1.07	.50	.16	.32	.47	5.86	.09	.97
4.0	.00	1.19	.35	.17	.44	.39	7.05	.05	.80
4.0	.00	1.22	.37	.15	.41	.37	7.43	.05	.76
4.0	.12	1.07	.42	.13	.31	.47	5.86	.07	.97
4.0	.12	1.07	.43	.12	.28	.47	5.86	.07	.97
4.0	.25	1.05	.37	.11	.28	.49	5.64	.07	1.01
4.0	.25	1.00	.38	.11	.28	.54	5.12	.07	1.11
3.0	.00	1.18	.26	.12	.44	.40	6.88	.04	.82
3.0	.00	1.17	.28	.12	.44	.40	6.88	.04	.82
3.0	.25	1.01	.31	.11	.35	.53	5.22	.06	1.09
3.0	.25	1.00	.30	.09	.30	.54	5.12	.07	1.11
3.0	.25	1.02	.28	.10	.34	.52	5.33	.05	1.06
2.5	.00	1.15	.22	.11	.50	.41	6.77	.03	.84
2.5	.00	1.19	.23	.12	.50	.39	7.05	.03	.80
2.5	.25	1.00	.28	.10	.34	.54	5.12	.05	1.11
2.5	.25	1.01	.27	.10	.37	.53	5.22	.05	1.09
2.5	.50	.91	.30	.07	.22	.65	4.24	.07	1.34
2.5	.50	.92	.30	.07	.23	.64	4.33	.07	1.31
2.0	.00	1.16	.18	.10	.53	.41	6.71	.03	.85
2.0	.00	1.19	.18	.09	.50	.39	7.05	.03	.80
2.0	.25	1.00	.21	.09	.40	.54	5.12	.04	1.11
2.0	.25	1.00	.21	.09	.38	.54	5.12	.04	1.11
2.0	.50	.90	.27	.05	.19	.66	4.15	.07	1.37
2.0	.50	.92	.25	.05	.20	.63	4.33	.06	1.31

Continuation

Series: A # Modules: 4 Water depth (d): 2.75 ft

e (in)	F	T (sec)	H_i (ft)	H_t (ft)	C_t	d/L	L (ft)	H_i/L	W/L
2.0	.75	.85	.28	.04	.13	.74	3.70	.08	1.53
2.0	.75	.82	.31	.03	.10	.80	3.44	.09	1.65
1.5	.00	1.17	.13	.08	.60	.40	6.88	.02	.82
1.5	.00	1.18	.13	.08	.72	.40	6.88	.02	.82
1.5	.25	1.00	.17	.07	.41	.54	5.12	.03	1.11
1.5	.25	1.00	.17	.07	.38	.54	5.12	.03	1.11
1.5	.50	.90	.20	.04	.21	.66	4.15	.05	1.37
1.5	.50	.92	.19	.04	.21	.63	4.35	.04	1.30
1.5	.75	.85	.23	.03	.14	.74	3.70	.06	1.53
1.5	.75	.84	.19	.03	.16	.76	3.61	.05	1.57
1.5	1.0	.79	.19	.02	.11	.86	3.20	.06	1.77
1.5	1.0	.77	.18	.02	.11	.91	3.05	.06	1.87
1.0	.00	1.20	.09	.06	.68	.38	7.24	.01	.78
1.0.	.00	1.20	.09	.06	.68	.38	7.24	.01	.78
1.0	.25	1.01	.12	.06	.46	.53	5.22	.02	1.09
1.0	.25	1.02	.12	.05	.45	.52	5.33	.02	1.06
1.0	.50	.90	.16	.03	.19	.66	4.15	.04	1.37
1.0	.50	.91	.15	.03	.18	.65	4.24	.04	1.34
1.0	.75	.84	.17	.03	.15	.76	3.61	.05	1.57
1.0	.75	.83	.16	.02	.13	.78	3.53	.05	1.61
1.0	1.0	.79	.13	.02	.13	.86	3.20	.04	1.77
1.0	1.0	.78	.12	.02	.15	.88	3.12	.04	1.82
.50	.00	1.19	.05	.04	.70	.39	7.05	.01	.80
.50	.00	1.19	.05	.04	.70	.39	7.05	.01	.80
.50	.25	1.00	.07	.04	.53	.54	5.12	.01	1.11
.50	.25	1.00	.07	.04	.54	.54	5.12	.01	1.11
.50	.50	.91	.09	.02	.19	.65	4.24	.02	1.34
.50	.50	.90	.10	.02	.16	.66	4.15	.02	1.37
.50	.75	.84	.11	.02	.14	.76	3.61	.03	1.57
.50	.75	.84	.11	.02	.18	.76	3.61	.03	1.57
.50	1.0	.77	.09	.01	.17	.91	3.05	.03	1.87
.50	1.0	.78	.09	.01	.15	.88	3.12	.03	1.82

Date: 5/21/78	Tested by: W. Nelson	
Series: A	# Modules: 3	Water depth (d):2.75 ft
Breakwater width (w): 4.5 ft	Seaward edge: Sta 55 ft	
Water temperature: 16.5° C	Air temperature: 18° C	
Mooring line turning sheaves:	#1 - Sta 33 ft	#2 - Sta 80 ft
y/d: 0.15		
Wave gages: H_i - Sta 44.5 ft	Attenuation X10	1 mm = .0128 ft
H_t - Sta 68 ft	Attenuation X10	1 mm = .0128 ft

e (in)	F	T (sec)	H_i (ft)	H_t (ft)	C_t	d/L	L (ft)	H_i/L	w/L
6.0	.00	1.18	.59	.32	.54	.40	6.88	.09	.65
6.0	.00	1.19	.63	.34	.54	.39	7.05	.09	.64
6.0	.10	1.12	.49	.30	.61	.43	6.42	.09	.70
6.0	.10	1.12	.46	.30	.65	.43	6.42	.07	.70
5.0	.00	1.18	.50	.27	.54	.40	6.88	.07	.65
5.0	.00	1.18	.52	.26	.50	.40	6.88	.08	.65
5.0	.12	1.08	.46	.23	.50	.46	5.97	.08	.75
5.0	.12	1.08	.49	.25	.50	.46	5.97	.08	.75
4.0	.00	1.18	.43	.19	.45	.40	6.88	.06	.65
4.0	.00	1.18	.43	.21	.49	.40	6.88	.06	.65
4.0	.25	1.0	.43	.17	.40	.54	5.12	.08	.88
4.0	.25	1.0	.40	.15	.39	.54	5.12	.08	.88
3.0	.00	1.18	.32	.17	.52	.40	6.88	.05	.65
3.0	.00	1.18	.32	.15	.48	.40	7.88	.05	.65
3.0	.25	1.01	.32	.12	.36	.53	5.22	.06	.86
3.0	.25	1.00	.31	.12	.39	.52	5.12	.06	.88
2.0	.00	1.20	.23	.12	.50	.38	7.24	.03	.62
2.0	.00	1.2	.26	.14	.54	.38	7.24	.04	.62
2.0	.25	1.00	.27	.09	.33	.52	5.12	.04	.88
2.0	.25	1.01	.27	.08	.31	.53	5.22	.05	.86
2.0	.50	.91	.26	.06	.24	.65	4.24	.06	1.06
2.0	.50	.91	.25	.06	.25	.65	4.24	.06	1.06
1.5	.00	1.18	.18	.10	.54	.40	6.88	.03	.65
1.5	.00	1.20	.19	.10	.54	.38	7.24	.03	.62
1.5	.25	1.01	.21	.06	.31	.53	5.22	.04	.86
1.5	.25	1.01	.18	.06	.33	.53	5.22	.03	.86
1.5	.50	.90	.22	.05	.23	.66	4.15	.05	1.08
1.5	.50	.90	.22	.05	.23	.66	4.15	.05	1.08
1.5	.75	.82	.25	.05	.21	.80	3.44	.07	1.31
1.5	.75	.83	.25	.04	.21	.78	3.53	.07	1.27

Continuation

Series: A # Modules: 3 Water depth (d): 2.75 ft

e (in)	F	T (sec)	H_i (ft)	H_t (ft)	C_t	d/L	L (ft)	H_i/L	w/L
1.0	.00	1.19	.14	.08	.55	.39	7.05	.02	..64
1.0	.00	1.18	.14	.07	.52	.40	6.88	.02	.65
1.0	.25	1.00	.15	.05	.35	.52	5.12	.03	.88
1.0	.25	1.00	.15	.05	.33	.52	5.12	.03	.88
1.0	.50	.90	.18	.05	.25	.66	4.15	.04	1.08
1.0	.50	.90	.19	.05	.24	.66	4.15	.05	1.08
1.0	.75	.85	.18	.05	.27	.74	3.7	.05	1.22
1.0	.75	.85	.18	.05	.25	.74	3.7	.05	1.22
1.0	1.0	.81	.19	.03	.14	.82	3.36	.06	1.34
1.0	1.0	.82	.19	.02	.o2	.80	3.44	.06	1.31
.50	.00	1.16	.07	.04	.52	.41	6.71	.01	.67
.50	.00	1.17	.06	.03	.48	.40	6.88	.01	.65
.50	.25	1.00	.08	.03	.39	.52	5.12	.02	.88
.50	.25	1.00	.08	.04	.47	.52	5.12	.02	.88
.50	.25	1.00	.08	.04	.43	.52	5.12	.02	.88
.50	.50	.90	.09	.03	.31	.66	4.15	.02	1.08
.50	.50	.90	.10	.03	.29	.66	4.15	.02	1.08
.50	.75	.83	.09	.03	.32	.78	3.53	.03	1.27
.50	.75	.83	.10	.03	.32	.78	3.53	.03	1.27
.50	1.0	.78	.13	.01	.10	.88	3.12	.04	1.44
.50	1.0	.76	.13	.01	.10	.93	2.96	.04	1.52

Date: 6/26/78	Tested by: W. Nelson
Series: A # Modules: 3	Water depth (d): 2.75 ft
Breakwater width (w): 4.5 ft	Seaward edge: Sta 55 ft
Water temperature: 16° C	Air temperature: 22° C
Mooring line turning sheaves: #1 - Sta 33 ft unrestrained lee	
y/d: 0.15	
Wave gages: H_i - Sta 45 ft	Attenuation X10 1 mm = .0103 ft
H_t - Sta 68 ft	Attenuation X10 1 mm = .0101 ft

e (in)	F	T (sec)	H_i (ft)	H_t (ft)	C_t	d/L	L (ft)	H_i/L	w/L
6.0	.00	1.20	.17	.09	.54	.38	7.2	.02	.63
6.0	.00	1.18	.15	.08	.53	.40	6.9	.02	.65
6.0	.12	1.09	.14	.06	.44	.46	6.0	.02	.75
6.0	.12	1.07	.14	.07	.47	.47	5.0	.02	.76
5.0	.00	1.20	.13	.06	.47	.38	7.2	.02	.63
5.0	.00	1.21	.13	.07	.51	.38	7.2	.02	.63
5.0	.12	1.08	.12	.05	.45	.46	6.0	.02	.75
5.0	.12	1.07	.12	.05	.43	.47	5.9	.02	.76
4.0	.00	1.18	.11	.05	.47	.40	6.0	.02	.65
4.0	.00	1.16	.11	.05	.45	.40	6.0	.02	.65
4.0	.25	1.01	.11	.04	.32	.53	5.2	.02	.87
4.0	.25	1.00	.11	.04	.33	.54	5.1	.02	.88
3.0	.00	1.15	.08	.04	.50	.40	6.8	.01	.66
3.0	.00	1.21	.09	.05	.51	.38	7.2	.01	.63
3.0	.25	.94	.09	.03	.28	.61	4.5	.02	1.00
3.0	.25	1.04	.09	.03	.28	.50	5.5	.02	.82
2.0	.00	1.18	.21	.12	.55	.40	6.9	.03	.65
2.0	.00	1.21	.19	.11	.58	.38	7.2	.03	.63
2.0	.25	1.01	.24	.06	.25	.53	5.2	.05	.87
2.0	.25	.97	.24	.06	.27	.57	4.8	.05	.94
2.0	.50	.94	.25	.05	.20	.61	4.5	.06	1.00
2.0	.50	.93	.26	.06	.23	.62	4.4	.06	1.02
1.5	.00	1.16	.13	.09	.69	.40	6.9	.02	.65
1.5	.00	1.16	.15	.10	.67	.40	6.9	.02	.65
1.5	.25	1.03	.14	.05	.36	.51	5.4	.03	.83
1.5	.25	1.01	.19	.06	.32	.53	5.2	.04	.87
1.5	.50	.92	.17	.04	.24	.64	4.3	.04	1.05
1.5	.50	.95	.15	.04	.27	.60	4.6	.03	.98
1.5	.75	.84	.15	.04	.27	.76	3.6	.04	1.25
1.5	.75	.88	.13	.03	.23	.69	4.0	.03	1.13
1.0	.50	.93	.11	.04	.32	.62	4.4	.03	1.02
1.0	.50	.92	.12	.04	.29	.64	4.3	.03	1.05
1.0	.75	.85	.16	.02	.15	.74	3.7	.04	1.22
1.0	.75	.82	.10	.01	.10	.81	3.4	.03	1.32

APPENDIX B

SERIES B DATA TABULATION

Date: 6/25/78		Tested by: W. Nelson
Series: B	# Modules: 6	Water depth (d): .33 ft
Breakwater width (w): 2.3 ft		Seaward edge: Sta 18.3 ft
Water temperature: 19° C		Air temperature: 20° C
Mooring line turning sheaves:	#1 - Sta 15 ft	#2 - Sta 24 ft
	y/d: 0.35	
Wave gages: H_i - Sta 14 ft	Attenuation X5	1 mm = .0061 ft
H_t - Sta 22 ft	Attenuation X5	1 mm = .0053 ft

e (in)	F	T (sec)	H_i (ft)	H_t (ft)	C_t	d/L	L (ft)	H_i/L	w/L
0.5	0.2	2.89	.015	.012	.80	.03	9.43	.00	.24
0.5	0.2	3.00	.014	.012	.82	.03	9.71	.00	.24
0.5	0.4	2.42	.026	.021	.81	.04	7.85	.00	.29
0.5	0.4	2.45	.024	.020	.83	.04	7.85	.00	.29
0.5	0.6	1.98	.036	.023	.64	.06	5.56	.01	.41
0.5	0.6	1.98	.034	.023	.68	.06	5.56	.01	.41
0.5	0.8	1.75	.034	.020	.59	.06	5.56	.01	.41
0.5	0.8	1.74	.034	.022	.65	.06	5.56	.01	.41
0.5	1.0	1.46	.037	.027	.74	.07	4.76	.01	.48
0.5	1.0	1.48	.038	.026	.69	.07	4.76	.01	.48
0.5	1.2	1.27	.043	.030	.71	.08	4.17	.01	.55
0.5	1.2	1.28	.042	.029	.70	.08	4.17	.01	.55
0.5	1.4	1.02	.040	.029	.73	.10	3.33	.01	.69
0.5	1.4	1.04	.040	.032	.79	.10	3.33	.01	.69
0.5	1.4	1.03	.040	.030	.76	.10	3.33	.01	.69
0.5	1.6	.83	.065	.038	.58	.14	2.38	.03	.97
0.5	1.6	.82	.065	.038	.58	.14	2.38	.03	.97
0.5	1.8	.64	.089	.034	.38	.19	1.75	.05	1.31
0.5	1.8	.65	.094	.033	.35	.18	1.85	.05	1.24
0.5	2.0	.54	.096	.025	.26	.24	1.39	.07	1.65
0.5	2.0	.55	.110	.024	.22	.24	1.39	.08	1.65
1.0	1.6	.87	.054	.029	.54	.13	2.6	.02	.88
1.0	1.6	.86	.053	.029	.55	.13	2.6	.02	.88
1.0	1.8	.64	.058	.022	.38	.10	1.8	.03	1.28
1.0	1.8	.66	.062	.022	.36	.18	1.9	.03	1.21
1.0	2.0	.54	.029	.007	.24	.25	1.4	.02	1.64
1.0	2.0	.53	.034	.008	.23	.25	1.4	.02	1.64

Date: 6/23/78	Tested by: W. Nelson	
Series: B	# Modules: 6	Water depth (d): .67 ft
Breakwater width (w): 2.3 ft	Seaward edge: Sta 19.75 ft	
Water temperature: 18.5° C	Air temperature: 19.5° C	
Mooring line turning sheaves:	#1 - Sta 15 ft	#2 - Sta 26 ft
y/d: 0.17		
Wave gages: H_i - Sta 14 ft	Attenuation X5	1 mm = .0065 ft
H_t - Sta 24 ft	Attenuation X5	1 mm = .0059 ft

e (in)	F	T (sec)	H_i (ft)	H_t (ft)	C_t	d/L	L (ft)	H_i/L	w/L
0.5	1.0	1.46	.052	.047	.91	.10	6.7	.01	.34
0.5	1.0	1.49	.052	.044	.85	.10	6.7	.01	.34
0.5	1.4	1.03	.064	.058	.90	.16	4.2	.02	.55
0.5	1.4	1.03	.064	.058	.90	.16	4.2	.02	.55
0.5	1.6	.81	.090	.064	.71	.23	2.9	.03	.79
0.5	1.6	.82	.090	.064	.71	.23	2.0	.03	.79
0.5	1.8	.67	.114	.056	.50	.30	2.2	.05	1.05
0.5	1.8	.67	.116	.058	.50	.30	2.2	.05	1.05
0.5	2.0	.54	.104	.024	.23	.44	1.5	.07	1.53
0.5	2.0	.55	.099	.023	.23	.44	1.5	.07	1.53
1.0	1.0	1.48	.107	.098	.92	.10	6.7	.02	.34
1.0	1.0	1.50	.104	.098	.95	.10	6.7	.02	.34
1.0	1.2	1.31	.107	.089	.83	.12	5.6	.02	.41
1.0	1.2	1.30	.105	.089	.86	.12	5.6	.02	.51
1.0	1.4	1.00	.148	.133	.89	.17	3.9	.04	.59
1.0	1.4	1.01	.150	.130	.86	.17	3.0	.04	.59
1.0	1.6	.82	.185	.136	.73	.23	2.9	.06	.79
1.0	1.6	.82	.189	.133	.70	.23	2.9	.07	.79
1.0	1.8	.65	.221	.106	.48	.31	2.2	.10	1.05
1.0	1.8	.66	.228	.103	.45	.31	2.2	.10	1.05
1.5	1.0	1.48	.182	.153	.85	.10	6.7	.03	.34
1.5	1.0	1.50	.182	.148	.81	.10	6.7	.03	.34
1.5	1.2	1.28	.156	.127	.81	.12	5.6	.03	.41
1.5	1.2	1.28	.159	.124	.78	.12	5.6	.03	.41
1.5	1.4	1.07	.176	.153	.87	.15	4.4	.04	.52
1.5	1.4	1.07	.179	.150	.84	.15	4.4	.04	.52
1.5	1.6	.85	.267	.183	.69	.21	3.2	.08	.72
1.5	1.6	.84	.280	.177	.63	.22	3.0	.09	.77
1.5	1.8	.67	.169	.083	.49	.30	2.2	.08	1.05
1.5	1.8	.67	.156	.083	.53	.30	2.2	.07	1.05

Date: 6/25/78	Tested by: W. Nelson
Series: B # Modules: 4	Water depth (d): .67 ft
Breakwater width (w): 1.5 ft	Seaward edge: Sta 19.75 ft
Water temperature: 20° C	Air temperature: 20° C
Mooring line turning sheaves: #1 - Sta 15 ft	#2 - Sta 25.5 ft
y/d: 0.17	
Wave gages: H_i - Sta 14 ft Attenuation x5	1 mm = .0061 ft
H_t - Sta 24 ft Attenuation x5	1 mm = .0056 ft

e (in)	F	T (sec)	H_i (ft)	H_t (ft)	C_t	d/L	L (ft)	H_i/L	w/L
0.5	1.0	1.52	.046	.045	.97	.101	6.63	.01	.23
0.5	1.0	1.46	.046	.045	.97	.10	6.7	.01	.22
0.5	1.2	1.25	.055	.050	.92	.12	5.6	.01	.27
0.5	1.2	1.24	.055	.053	.96	.12	5.6	.01	.27
0.5	1.4	1.05	.070	.053	.76	.16	4.2	.02	.36
0.5	1.4	1.04	.067	.050	.75	.16	4.2	.02	.36
0.5	1.6	.84	.082	.067	.82	.22	3.0	.03	.50
0.5	1.6	.83	.082	.067	.82	.22	3.0	.03	.50
0.5	1.8	.65	.113	.062	.55	.31	2.2	.05	.68
0.5	1.8	.64	.116	.059	.51	.33	2.0	.06	.75
0.5	2.0	.53	.092	.039	.43	.48	1.4	.09	1.07
0.5	2.0	.53	.095	.036	.38	.48	1.4	.07	1.07
1.0	1.0	1.51	.107	.098	.92	.10	6.7	.02	.22
1.0	1.0	1.49	.104	.092	.89	.10	6.7	.02	.22
1.0	1.2	1.24	.110	.101	.92	.12	5.6	.02	.27
1.0	1.2	1.27	.107	.101	.94	.12	5.6	.02	.27
1.0	1.4	1.02	.140	.115	.82	.17	3.9	.04	.38
1.0	1.4	1.05	.134	.115	.86	.16	4.2	.03	.36
1.0	1.6	.83	.162	.137	.85	.22	3.0	.05	.50
1.0	1.6	.83	.156	.134	.86	.22	3.0	.05	.50
1.0	1.8	.66	.201	.129	.64	.31	2.2	.09	.68
1.0	1.8	.65	.201	.118	.59	.31	2.2	.09	.68
1.5	1.0	1.48	.177	.154	.87	.10	6.7	.03	.22
1.5	1.0	1.47	.171	.146	.85	.10	6.7	.03	.22
1.5	1.2	1.27	.186	.146	.78	.12	5.6	.03	.27
1.5	1.2	1.26	.177	.157	.89	.12	5.6	.03	.27
1.5	1.2	1.28	.180	.151	.84	.12	5.6	.03	.27
1.5	1.4	1.05	.201	.174	.86	.16	4.2	.05	.36
1.5	1.4	1.04	.198	.171	.86	.16	4.2	.05	.36
1.5	1.6	.85	.220	.190	.86	.21	3.2	.07	.47
1.5	1.6	.83	.232	.196	.85	.22	3.0	.08	.50

Date: 6/26/78	Tested by: W. Nelson	
Series: B	# Modules: 3	Water depth (d): .67 ft
Breakwater width (w): 1.1 ft	Seaward edge: Sta 19.5 ft	
Water temperature: 19° C	Air temperature: 20.5° C	
Mooring line turning sheaves:	#1 - Sta 15 ft	#2 - Sta 25 ft
y/d: 0.17		
Wave gages: H_i - Sta 14 ft	Attenuation X5	1 mm = .0058 ft
H_t - Sta 24 ft	Attenuation X5	1 mm = .0056 ft

e (in)	F	T (sec)	H_i (ft)	H_t (ft)	C_t	d/L	L (ft)	H_i/L	w/L
0.5	1.0	1.46	.044	.042	.96	.10	6.7	.01	.16
0.5	1.0	1.46	.044	.042	.96	.10	6.7	.01	.16
0.5	1.2	1.28	.070	.062	.88	.12	5.6	.01	.19
0.5	1.2	1.28	.064	.059	.92	.12	5.6	.01	.19
0.5	1.4	1.04	.078	.056	.72	.16	4.2	.02	.26
0.5	1.4	1.04	.078	.056	.72	.16	4.2	.02	.26
0.5	1.6	.87	.073	.053	.73	.20	3.3	.02	.33
0.5	1.6	.84	.073	.053	.73	.22	3.0	.02	.36
0.5	1.8	.66	.125	.064	.52	.31	2.2	.06	.49
0.5	1.8	.68	.128	.064	.50	.29	2.3	.06	.47
0.5	2.0	.54	.116	.045	.39	.44	1.5	.08	.72
0.5	2.0	.54	.122	.045	.37	.44	1.5	.08	.72
1.0	1.0	1.52	.099	.092	.93	.10	6.7	.01	.16
1.0	1.0	1.49	.096	.092	.96	.10	6.7	.01	.16
1.0	1.2	1.28	.133	.104	.78	.12	5.6	.02	.19
1.0	1.2	1.29	.133	.104	.78	.12	5.6	.02	.19
1.0	1.4	1.04	.157	.112	.71	.16	4.2	.04	.26
1.0	1.4	1.03	.162	.118	.73	.16	4.2	.04	.26
1.0	1.6	.80	.162	.129	.80	.23	2.9	.06	.37
1.0	1.6	.79	.157	.123	.79	.23	2.9	.05	.37
1.5	1.0	1.52	.165	.148	.90	.10	6.7	.02	.16
1.5	1.0	1.49	.160	.143	.89	.10	6.7	.02	.16
1.5	1.2	1.28	.194	.162	.84	.12	5.6	.03	.19
1.5	1.2	1.27	.200	.171	.85	.12	5.6	.04	.19
1.5	1.4	1.03	.226	.157	.69	.16	4.2	.05	.26
1.5	1.4	1.04	.240	.174	.70	.16	4.2	.06	.26

Date: 6/26/78	Tested by: W. Nelson	
Series: B	# Modules: 3	Water depth (d): .67 ft
Breakwater width (w): 1.1 ft	Seaward edge: Sta 19.5 ft	
Water temperature: 19° C	Air temperature: 21° C	
Mooring line turning sheaves: #1 - Sta 15 ft unrestrained lee		
y/d: 0.17		
Wave gages: H_i - Sta 14 ft	Attenuation X5	1 mm = .0058 ft
H_t - Sta 24 ft	Attenuation X5	1 mm = .0056 ft

e (in)	F	T (sec)	H_i (ft)	H_t (ft)	C_t	d/L	L (ft)	H_i/L	w/L
0.5	1.0	1.48	.046	.045	.97	.10	6.7	.01	.16
0.5	1.0	1.50	.041	.030	.96	.10	6.7	.01	.16
0.5	1.2	1.30	.058	.050	.86	.12	5.6	.01	.19
0.5	1.2	1.28	.058	.050	.86	.12	5.6	.01	.19
0.5	1.4	1.02	.064	.056	.88	.17	3.9	.02	.28
0.5	1.4	1.03	.067	.056	.84	.16	4.2	.02	.26
0.5	1.6	.85	.087	.076	.87	.21	3.2	.03	.34
0.5	1.6	.82	.090	.078	.87	.23	3.2	.03	.34
0.5	1.8	.65	.131	.076	.58	.31	2.2	.06	.49
0.5	1.8	.63	.128	.073	.57	.34	2.0	.06	.54
0.5	2.0	.52	.116	.045	.30	.44	1.4	.08	.77
0.5	2.0	.54	.116	.045	.39	.44	1.5	.09	.72
1.0	1.0	1.49	.110	.106	.97	.10	6.7	.02	.16
1.0	1.0	1.49	.107	.104	.97	.10	6.7	.02	.16
1.0	1.2	1.28	.119	.109	.92	.12	5.6	.02	.19
1.0	1.2	1.28	.122	.112	.92	.12	5.6	.02	.19
1.0	1.4	1.05	.139	.126	.91	.16	4.2	.03	.26
1.0	1.4	1.04	.136	.126	.93	.16	4.2	.03	.26
1.0	1.6	.83	.212	.162	.77	.22	3.0	.07	.36
1.0	1.6	.31	.209	.162	.78	.23	2.9	.07	.37
1.5	1.0	1.46	.160	.162	1.0	.10	6.7	.02	.16
1.5	1.2	1.30	.171	.179	1.0	.12	5.6	.03	.19
1.5	1.4	1.03	.226	.196	.87	.16	4.2	.05	.26

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c.1 An investigation into the scaling confidence of floating tire breakwater model tests.